

National Biodiversity Assessment 2018

TECHNICAL REPORT

Volume 6:

sub-Antarctic Territory



King Penguins on Marion Island in South Africa's sub-Antarctic Territory. Photo: Otto Whitehead.

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For reference in non-scientific publications

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Volume 1. Terrestrial

Skowno, A.L., Raimondo, D.C., Poole, C.J., Fizzotti, B., and Slingsby, J.A. (eds). 2019. *South African National Biodiversity Assessment 2018 Technical Report Volume 1: Terrestrial Realm*. South African National Biodiversity Institute, Pretoria.

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Volume 7. Genetics

Tolley, K.A., Da Silva, J.M. and Jansen van Vuuren, B. 2019. *South African National Biodiversity Assessment 2018 Technical Report Volume 7: Genetic Diversity*. South African National Biodiversity Institute, Pretoria. <http://hdl.handle.net/20.500.12143/6376>

OTHER ANNEXURES

Each technical report listed has a number of annexures such as inventory reports, method explanations, and both spatial and non-spatial datasets, available at <http://biodiversityadvisor.sanbi.org>

Three other independent annexures exist as supplementary material for NBA 2018:

- SANBI. 2019. *National Biodiversity Assessment 2018 Supplementary Material: Compendium of Benefits of Biodiversity*. South African National Biodiversity Institute, Pretoria.
- SANBI. 2019. *South Africa's National Biodiversity Assessment: Contextual and Operational Framework. Released as supplementary material to the National Biodiversity Assessment 2018*. South African National Biodiversity Institute, Pretoria.
- SANBI. 2019. *National Ecosystem Classification System. Released as supplementary material to the National Biodiversity Assessment 2018*. South African National Biodiversity Institute, Pretoria.

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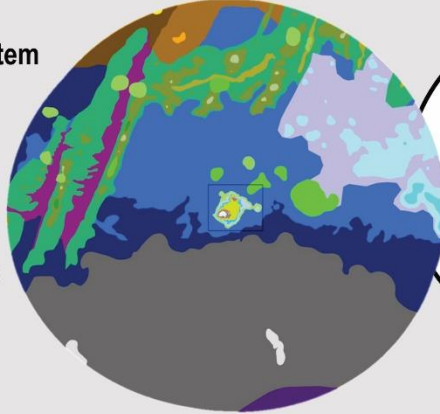
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EXECUTIVE SUMMARY

This first inclusion of the sub-Antarctic territory in South Africa's National Biodiversity Assessment provided a seamless map of 34 ecosystem types and assessed their threat status and protection level. Decades of research conducted at the Prince Edward Islands (PEIs) by a network of institutions, have placed South Africa at the forefront of global change studies in sub-Antarctic and Antarctic science. Knowledge gaps and research priorities in the sub-Antarctic are identified to strengthen the science base for future assessments.

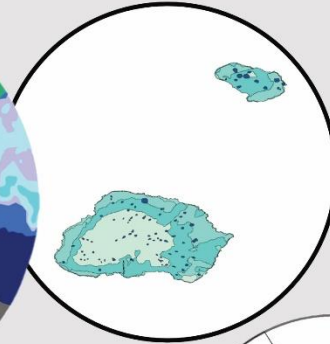
29 Marine ecosystem types nested within 4 ecoregions:

- PEI Temperate
- PEI sub-Antarctic Front
- PEI Polar Front
- Ob and Lena Polar Front



5 Terrestrial vegetation types have been mapped in 2 biomes:

- Polar Desert
- sub-Antarctic Tundra



PRESSURES: Patagonian Toothfish fishery

The typical pressures affecting mainland marine and terrestrial ecosystem types are absent but the Patagonian toothfish fishery is a key pressure in the marine environment. **The extent of longline fishing was mapped and used to inform ecosystem assessments.**



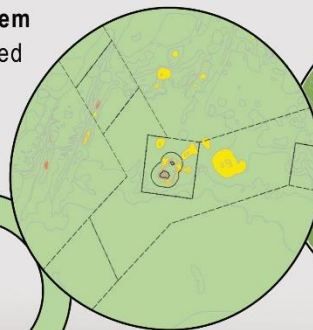
THREAT STATUS

21% of marine ecosystem types are threatened by fishing.

All 5 Terrestrial vegetation types are **Data Deficient**

5 Marine ecosystem types are **Endangered**

1 Marine ecosystem type is **Vulnerable**



23 Marine ecosystem types are **Least Concern**.

PROTECTION LEVEL

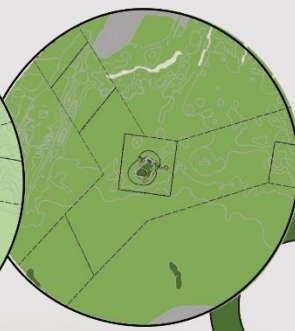
36% of the sub-Antarctic territory's oceans are in an MPA with 5% of the EEZ zoned to exclude fishing.

10 Marine and all 5 terrestrial ecosystem types are **Well Protected**

14 Marine ecosystem types are **Moderately Protected**

1 Marine ecosystem type is **Poorly Protected**

4 Marine ecosystem types are **Not Protected**

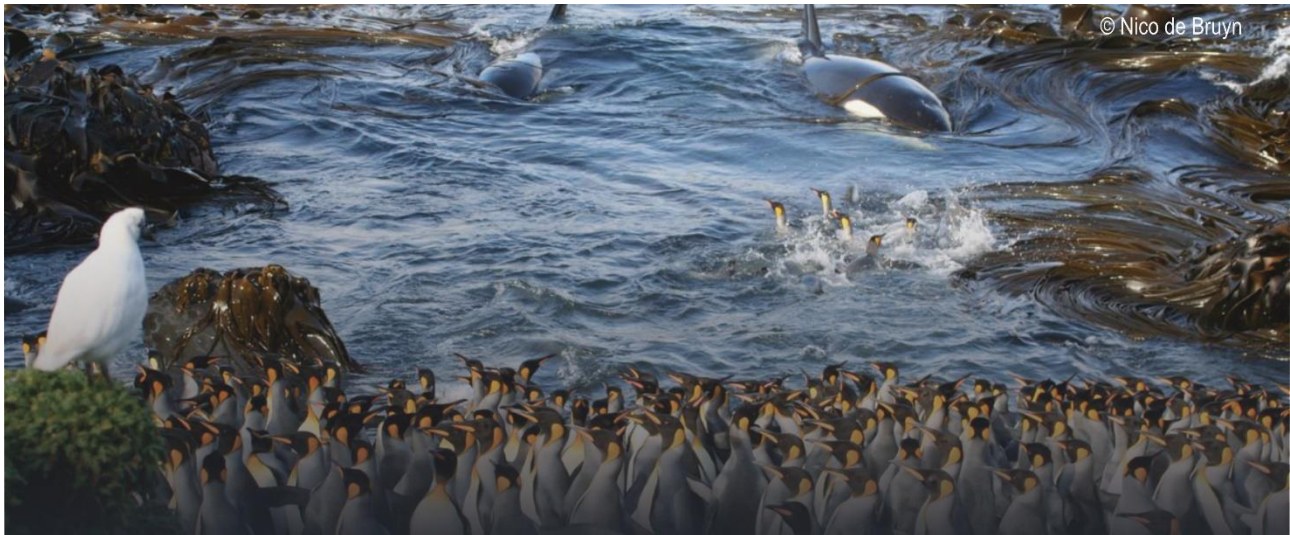


Priority Actions: South Africa must continue to maintain its high standard of research, collaboration and opportunities for scientific capacity development in order to address critical knowledge gaps that limit the assessment of sub-Antarctic biodiversity.

Priority Actions: Reduce fishing impacts and improve MPA zonation.



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The sub-Antarctic territory supports an incredible diversity of marine and terrestrial life not found on mainland South Africa or in its surrounding oceans. There is insufficient data to perform species assessments on most groups, but an assessment of the birds at the island revealed that 28 of 29 species are Threatened or Near Threatened.



The key threats to biodiversity at the sub-Antarctic are climate change and invasive species.

INVASIVE SPECIES



The sub-Antarctic realm has been threatened by terrestrial invasive species including **27 invertebrates, 1 fungus, 17 plant species and 1 vertebrate** - the House Mouse.

- The house mouse population has increased **430% in 30 years** and has had devastating impacts on terrestrial biodiversity.
- Mice have impacted the **2.5 million pairs of breeding seabirds**, causing up to **100% mortality** in affected seabird chicks.
- Mice have depleted seed stocks and caused dieback of vegetation while excessive invertebrate predation has resulted in an **85% decline** in invertebrate biomass.

Priority Actions: Eradicate the invasive House Mouse from Marion Island and prevent future biological invasions.



CLIMATE CHANGE

Air and sea temperatures have warmed by 1.2 and 1.4°C since 1950.

- Wind patterns have changed, with NW winds becoming more common, resulting in a 34% decrease in rainfall in the last 50 years.
- The permanent snow line has disappeared and ice cover on the plateau has retreated.
- Local currents have strengthened, reducing local productivity and changing the composition of benthic communities.
- Many terrestrial plants have expanded their ranges, including alien species.

Priority Actions: Maintain and increase critical and other global change time series data by investing in climate change research.

Research Gaps: Climate change and invasive species exacerbate other pressures. Further research is needed to understand these complex compounding interactions



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EXECUTIVE SUMMARY

The National Biodiversity Assessment (NBA) 2018 is a collaborative effort to synthesise the best available science on South Africa's biodiversity. The overarching aim of the NBA is to inform policy and decision-making in a range of sectors, and contribute to national development priorities. The NBA is used to inform policy in the biodiversity sector and other sectors that rely on and/or impact the environment and associated natural resources, such as agriculture and fisheries, water, mining, transport and human settlements. The NBA provides information to help prioritise effort and resources for managing and conserving biodiversity, and provides context and information that underpins biodiversity inputs to spatial and other planning processes. A range of national and international level monitoring, reporting and assessment processes rely on information gathered during the NBA. The NBA is also a key reference and educational product relevant to scientists, students, consultants and decision makers, and acts as a national level platform for collaboration, information sharing and capacity building in the biodiversity sector in South Africa. This is a cross realm report on the state of terrestrial and marine biodiversity within South Africa's sub-Antarctic territory with similar reports covering the Terrestrial, Mainland Marine, Inland Aquatic (Rivers and Wetlands), Coastal and Estuarine realms, as well as a special report on Genetic Diversity.

For the first time, South Africa's southernmost territory, the Prince Edward Islands (PEIs), the surrounding territorial sea and Exclusive Economic Zone have been included in the NBA. South Africa is the only African country with territory in the sub-Antarctic, comprising Prince Edward Island (45 km²) and the larger Marion Island (270 km²) with approximately 475 000 km² of surrounding ocean territory that extends 200 nautical miles (370 km) offshore. The Prince Edward Islands (PEIs) are located in the Indian Ocean Sector of the Southern Ocean, approximately 1 700 km southeast of mainland South Africa. The PEIs lie directly in the path of the Antarctic Circumpolar Current and between two productive frontal systems, the Sub-Antarctic Front and the Antarctic Polar Front. The terrestrial and marine ecosystems support unique biodiversity not found anywhere on the South African mainland or in its surrounding oceans. This report focuses on the ecosystem component of biodiversity with further effort needed to report at the species and genetic level in future assessments. Pressures and threats to biodiversity are reviewed and key actions are identified to maintain and improve the state of South Africa's sub-Antarctic biodiversity. The Threat Status of ecosystems and some species is discussed and Ecosystem Protection Levels reported for the first time. As this is the first assessment, no trends could be evaluated, however, this report provides a baseline from which to track the state of biodiversity in South Africa's sub-Antarctic territory.

A first map of 34 ecosystem types in South Africa's sub-Antarctic territory was developed, supporting a greater understanding of biodiversity patterns and providing a foundation for a systematic assessment of all marine and terrestrial ecosystem types. On the islands, **five terrestrial ecosystem types** were previously described in two biomes: sub-Antarctic Tundra and Polar Desert. Challenges remain in mapping these types at an appropriate scale that both accounts for their complexity but facilitates ecosystem assessment using a global approach. A first map of **29 marine ecosystem types** nested within four benthic-pelagic ecoregions was produced to address the long recognised research priority to include the 475 000 km² sub-Antarctic territory in the assessment of marine biodiversity. Marine ecosystem classification and mapping was based on extensive research, consolidating historical and current information on benthic and pelagic ecoregions. These included long-term positions of major oceanographic frontal systems, research on bathymetry, the seabed and biodiversity patterns. The 29 ecosystem types comprised multiple shore types, shelf types, and ecosystem types from the slope, plateau, ridges, seamounts, rift valleys and abyss. Additional fine-scale descriptive elements of the classification were developed delineating kelp habitats, areas of pelagic habitat importance for top predator foraging, and incidence records of Vulnerable Marine Ecosystem (VME) indicator

taxa. As in the coast of mainland South Africa, the marine and adjacent terrestrial ecosystem types align seamlessly at the land-sea interface. The majority of the marine and terrestrial ecosystem types described are likely to occur on and around other sub-Antarctic islands, indicating the need for collaborative regional work in ecosystem classification and mapping, indicating the need for more regional collaboration in ecosystem classification, mapping and assessment.

The Patagonian Toothfish (*Dissostichus eleginoides*) fishery is a key pressure in the marine environment of the PEIs. Biodiversity concerns associated with the fishery include historical overfishing, stock status concerns, interactions with seabirds and marine mammals and longline impacts to the seabed particularly for Vulnerable Marine Ecosystems (VMEs). The intensity and extent of longline fishing for Patagonian Toothfish was mapped using data available since the experimental fishery began in 1996. The total number of hooks set (fishing effort) was used to map the fishing footprint between 1996 and 2016. Although the original design of the PEI Marine Protected Area recommended the exclusion of fishing for Patagonian Toothfish from four restricted zones, toothfish longlining is permitted in three of the four restricted zones where toothfish occur.

The first national assessment of the Ecosystem Threat Status of marine ecosystem types found that 21% of types are threatened by historic or current fishing, including one Endangered ecosystem type and five Vulnerable ecosystem types. Terrestrial ecosystems are currently Data Deficient. Terrestrial and marine ecosystems were assessed using the International Union for Conservation of Nature (IUCN) Red List of Ecosystems (RLE) guidelines, and this first attempt at a national assessment in the sub-Antarctic territory has highlighted knowledge gaps and research priorities. Priority research areas include more information on the impacts of climate change, invasive species and Toothfish fishing to improve quantification of degradation and improved assessment of ecosystem condition. Although terrestrial ecosystems are free from typical mainland pressures (e.g. land clearing for croplands, human settlements and disturbance), biological invasions and climate change have caused major changes in recent decades. Both threats are the subject of ongoing research and in the near future a regional assessment of terrestrial Ecosystem Threat Status will be possible. Regional assessments will require additional ecosystem mapping efforts and research on nearby islands. It is important to determine which, if any, ecosystem types in the sub-Antarctic territory do not occur elsewhere. Global or regional assessments may be important when the full extent of ecosystem types are better understood.

Thirty-six per cent of South Africa's sub-Antarctic territory is included in the Marine Protected Area (MPA), and six per cent of the EEZ is zoned to exclude fishing for commercially important Patagonian Toothfish. A first assessment of Ecosystem Protection Levels revealed that 10 of 29 (34%) marine ecosystems are Well Protected, 14 are Moderately Protected, one is Poorly Protected and four are Not Protected. All five of the terrestrial ecosystem types are Well Protected in the Special Nature Reserve and RAMSAR Wetland of International Importance. Regional assessments are needed to better understand Protection Levels for ecosystem types that also occur beyond South Africa's sub-Antarctic territory. It is recommended that fishing in the MPA should be reduced and regulations specifying fishing effort (hook numbers) in restricted zones be re-evaluated.

South Africa's sub-Antarctic territory supports abundant marine and terrestrial biodiversity and provides critical breeding grounds for seals and globally threatened seabirds. There are three seal species, four penguin species, five albatross species, 14 petrel species, five other seabird species, and one terrestrial bird species that breed on the island. Several of these species are taxa of conservation concern and **28 seabird species are Threatened or Near-Threatened.** Many plant species are regional endemics. Research on the ocean shelf ecosystems has recorded highly diverse assemblages on the seabed, with many having great

potential for bioprospecting. Future work at species and genetic levels is needed to improve biodiversity assessments in this region.

Invasive species are a major threat to sub-Antarctic biodiversity, and South Africa is poised to eradicate the most problematic invasive species at Marion Island – the House Mouse. Once completed, this will be the largest island-wide rodent eradication in the world. The terrestrial ecosystems of the PEIs have been impacted by invasive plants, invertebrates and mammals, but invasive House Mouse is the most concerning. At Marion Island, mice have caused ecosystem-wide impacts to terrestrial ecosystems, depleting macroinvertebrate populations and seed stock and, more recently, predating on seabird chicks and eggs. The presence and impact of marine invasive species in the sub-Antarctic territory is poorly understood due to limited research on this topic. However, this is an emerging concern in the Southern Ocean and therefore focused research is needed to predict and detect potential alien and invasive species. To reduce threats to sub-Antarctic ecosystems and species, it is vital that problematic invasive species are eradicated, using the most ethical methods available that will pose the least threat to the biodiversity of the islands, and future invasions prevented.

Climate change is a serious threat to sub-Antarctic biodiversity with mean annual air and sea temperatures increasing at twice the mean global rate. Changes in the marine environment at the PEIs are largely driven by the Antarctic Circumpolar Current and its associated fronts, particularly the Sub-Antarctic Front that has shifted southward. Warmer waters and faster currents have become more common near the islands, reducing local productivity and changing the trophic structure and composition of benthic communities. Epipelagic communities near the islands have changed in species composition, with Antarctic species decreasing and sub-Tropical species becoming more common. As the Antarctic Circumpolar Current and its associated fronts continue to migrate poleward, eddy generation at the Southwest Indian Ridge is predicted to decrease, reducing the advection of zooplankton and micronekton to the PEIs. These changes have most impacted short to medium-range predators – including Gentoo (*Pygoscelis papua*), Macaroni (*Eudyptes chrysolophus*) and Rockhopper Penguins (*Eudyptes chrysocome*) and the Crozet Shag – that have declined in recent decades.

Warmer air temperatures and more northerly winds have coincided with a considerable drying of the islands, with a 34% decrease in rainfall observed since 1970. This has directly impacted the ecology of many terrestrial taxa, which evolved under a cool and wet sub-Antarctic climate. Impacts on native species include range expansions, especially to higher (and cooler) altitudes. Warmer and drier conditions have exacerbated the spread of alien invasive species, particularly the House Mouse, and compounded their negative effect on native species. This is expected to worsen with continued warming.

Decades of research conducted at the PEIs by a network of institutions, have placed South Africa at the forefront of sub-Antarctic and Antarctic science, highlighting the important role of the PEIs as a natural laboratory for global change studies. The upgraded research station at Marion Island and the dedicated Antarctic research vessel, the *SA Agulhas II*, have allowed scientists to conduct novel research at the islands and in the surrounding ocean territory. The inclusion of the sub-Antarctic in this NBA provides a valuable resource for regular reporting of past and current research at the islands, which may ultimately contribute to the management and protection of their unique biodiversity. This first attempt at a national ecosystem assessment highlights knowledge gaps and research priorities for the sub-Antarctic research community. Addressing these priorities will strengthen the science and provide an increasingly effective baseline for the assessment and management of biodiversity in our southernmost territory.

Five high level priority actions are identified to address the key findings of this assessment with links to existing policy, plans and frameworks. The links between these and the National Biodiversity Strategy and Action Plan (NBSAP) and the National Biodiversity Framework (NBF) are explained. Priority actions span the knowledge-action continuum and cover key actions to improve assessment of ecosystem and species status, avoid further ecosystem degradation and impacts on priority species. The five most urgent priority actions for terrestrial and marine biodiversity in South Africa's sub-Antarctic territory are:

- **Eradicate the invasive House Mouse from Marion Island**
- **Prevent future biological invasions**
- **Reduce fishing impacts in the Prince Edward Islands Marine Protected Area**
- **Maintain and increase critical time series for climate and global change research and manage for climate resilience**
- **Address critical knowledge gaps that limit the assessment of sub-Antarctic biodiversity**

A key aspect of mobilising resources and management action to address these priorities includes the need to effectively communicate the value of South Africa's sub-Antarctic biodiversity, through improved co-ordinated messaging that articulates the biodiversity benefits in this globally important region. These include carbon sequestration and climate regulation, fisheries benefits, bio-discovery potential and the valuable research assets that are provided by this natural laboratory that can help understand global change. The key knowledge gaps and limitations from the NBA 2018 biodiversity assessment were identified and discussed. Additional priority actions to address the knowledge gaps and research priorities are communicated. These span foundational biodiversity research at the ecosystem, species and genetic level, research to improve the understanding of key pressures and ecosystem condition, research and collaboration to mitigate the threat of illegal fishing as well as monitoring priorities. Addressing these gaps will help improve future biodiversity assessments, improving confidence and reducing uncertainty to effectively inform policy, management and action for improvements in the status of sub-Antarctic biodiversity.

1. INTRODUCTION AND APPROACH

Adams, R., van der Merwe, S., Skowno, A., Sink, K.J., von der Meden, C., and Whitehead, T.O. 2019. '1: Introduction and Approach', in *National Biodiversity Assessment 2018 Technical Report Volume 6: sub-Antarctic Territory*. Whitehead, T.O., Von der Meden, C., Skowno, A.L., Sink, K.L., van der Merwe, S., Adams, R. and Holness, S. (eds.). South African National Biodiversity Institute, Pretoria.



King penguins at Ship's Cove, Marion Island. Changing frontal positions are a major climate change concern for breeding top predators that rely on productivity related to the interactions of fronts with fixed topographic features Photo: Otto Whitehead.

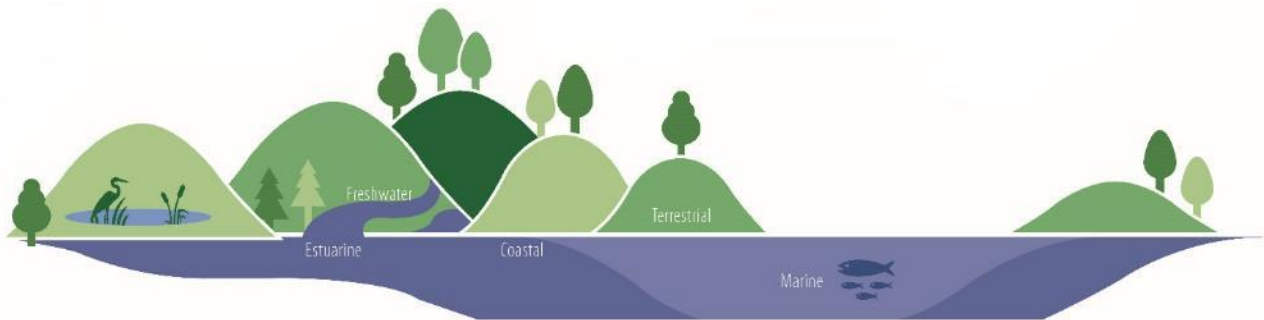
The National Biodiversity Assessment (NBA) is a collaborative effort to synthesise and present the best available science on South Africa's biodiversity. It aims to inform policy, planning and decision making in a range of sectors for the conservation and sustainable use of biodiversity.

The NBA is a platform for reporting on the current state of biodiversity within South Africa. It describes the key pressures on biodiversity and, where possible, identifies important trends. It covers the Terrestrial, Inland Aquatic¹ (Rivers and Wetlands), Estuarine and Marine realms, as well as the coast and South Africa's sub-Antarctic territory as cross-realm zones. The NBA is used to illustrate the benefits that biodiversity and intact ecosystems provide to the economy, society and human wellbeing. Finally, the systematic approach of the NBA allows us to identify important national knowledge gaps and research priorities linked to biodiversity.

Biodiversity is defined as the 'variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and across ecosystems' (Convention on Biological Diversity).



Biodiversity incorporates diversity at the genetic, species and ecosystem level – which together form the foundation of ecosystem services and are integrally linked to human wellbeing.



The NBA covers all four realms: terrestrial, inland aquatic (freshwater), estuarine and marine; and the coast. It also includes South Africa's sub-Antarctic territory.

Purpose and structure of the NBA

The NBA is the primary tool for monitoring and reporting on the state of biodiversity in South Africa. It is prepared as part of the South African National Biodiversity Institute's (SANBI) mandate² to monitor and report regularly on the status of South Africa's biodiversity, and is a collaborative effort from many institutions and individuals. The NBA focusses primarily on assessing biodiversity at the ecosystem and species level, with efforts being made to include genetic level assessments. Two headline indicators that are applied to both ecosystems and species are used in the NBA: Threat Status and Protection Level. The products of the NBA include seven technical reports, a technical synthesis report and several popular outputs.

The primary **purpose** of the NBA is to provide a high-level summary of the state of South Africa's biodiversity at regular points in time, with a strong focus on spatial information. Each NBA builds on decades of research

¹ Inland aquatic realm refers to rivers and inland wetlands. The term 'freshwater realm' is regularly used in the biodiversity sector but since numerous inland saline wetland ecosystems occur in South Africa the term 'inland aquatic' is preferred. The term 'inland wetland' is used to distinguish these ecosystems from estuarine or marine wetlands which are considered part of the estuarine and marine realms respectively.

² SANBI's mandate is outlined in the National Environmental Management: Biodiversity Act (10 of 2004), hereafter referred to as the 'Biodiversity Act'.

and innovation by South African scientists, and makes that science available in a useful form to users both inside and outside of the biodiversity sector. As a body of work the NBA is not prescriptive; it presents important information that can be adopted by government and civil society in various decision-making processes to support socio-economic imperatives, human wellbeing, and the best management of South Africa's biodiversity.

Like the previous assessments in 2004 and 2011, this third iteration of the NBA will feed into a range of processes within the environmental sector and beyond (Figure 1). Key applications include:

- Informing policies and strategies in the biodiversity sector (e.g. National Biodiversity Framework, National Protected Area Expansion Strategy), and other key sectors responsible for natural resources utilisation and/or protection, such as the water, agriculture, fisheries, and mining sectors (e.g. Mining and Biodiversity Guidelines).
- Providing information to help prioritise the often limited resources for managing and conserving biodiversity; including datasets that feed into site and regional level planning and assessment (e.g. Strategic Environmental Assessments and Environmental Impact Assessments) and provincial and municipal Bioregional Plans and Marine Spatial Plans (i.e. systematic biodiversity planning).
- Creating a key reference and educational work for use by scientists, students, consultants, decision makers and funders.
- Serving as an effective national level platform for encouraging and facilitating collaboration, information sharing and, importantly, capacity building in the biodiversity sector in South Africa.
- Providing information for a range of national and international level monitoring, reporting and assessment processes such as state of environment reporting and reporting on commitments to international conventions (e.g. linked to the United Nations Convention on Biological Diversity [CBD], the Sustainable Development Goals [SDGs] and the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services [IPBES]).



Figure 1. International reporting processes and channels into which the NBA is a key informant. Including international conventions signed by the South African Government and voluntary processes.

Navigating the NBA products

The NBA has a varied audience each with different needs, hence the NBA is presented in various forms. The NBA website is the primary portal through which you can access all information and products [<http://biodiversityadvisory.sanbi.org>]. The NBA website also provides factsheets and presentations summarising the NBA for non-technical audiences, using graphics and accessible language.

The NBA 2018 has **seven technical reports**: one for each realm (Terrestrial, Inland Aquatic, Estuarine and Marine); two cross-realm technical reports (the coast and **South Africa's sub-Antarctic territory**); and a technical report on Genetic Diversity. The technical reports are comprehensive volumes covering all input data used for the assessments, detailed explanations of methods and approach, full results and discussion, key messages for decision makers, limitations and knowledge gaps, and priorities for the future. These reports are for a scientific and technical audience, and are fully referenced and peer reviewed. The technical reports refer to various supplementary technical documents, maps and datasets; all of which are available through the NBA website with accompanying metadata. A synthesis report was produced that focuses on the main findings and key messages from each technical report (Skowno *et al.* 2019).

The NBA process

The breadth and scope of the NBA make collaboration between multiple institutions and individuals an essential part of the process. The South African National Biodiversity Institute (SANBI) plays the lead role and facilitates contributions by a large pool of experts. The collaboration ensures that the best available science underpins the NBA, promotes collective ownership of the NBA products by the biodiversity community in South Africa, and helps ensure a common vision for action following the assessment. The vast majority of contributions to the NBA are voluntary, and the few formal funded contributions involve significant co-financing. Without these voluntary contributions from experts and institutions outside of SANBI, the creation of the NBA would not be possible. While the reliance on experts to contribute voluntarily does present significant risks to the process, paid alternatives bring their own challenges and budget constraints.

Various internal and external governance structures were put in place in 2015 to guide the NBA 2018, ensure the project received adequate oversight, and provide structures for the consultation of a wide range of experts in each specific biodiversity field. The reference groups included researchers, experts and officials with technical roles, while the steering and advisory committees included senior officials. The NBA 2018 process focused particularly on increasing cross-realm collaboration, which led to better alignment between realms for input data, assessment approaches and explanation of areas for improvement.

Units of assessment and headline indicators

Headline indicators: Threat Status and Protection Level for species and ecosystems

Biodiversity indicators have received renewed attention recently amid calls to slow global losses of biodiversity (Nicholson *et al.* 2012, Tittensor *et al.* 2014, Geijzendorffer *et al.* 2015). Indicators in general, are a tool to i) improve general awareness and gain public attention for biodiversity; ii) meet international reporting requirements; iii) monitor conservation actions; and iv) inform policy and decision-making by governments (Nicholson *et al.* 2012, 2015, Keith *et al.* 2013, 2015, Geijzendorffer *et al.* 2015, Tanentzap *et al.* 2017).

The NBA relies on two **headline indicators** that can be applied to both ecosystems and species; **Threat Status** and **Protection Level**. The first indicator (Threat Status) is based on the IUCN risk assessment framework for species (Red List of Species) (IUCN 2012) and ecosystems (Red List of Ecosystems) (Bland *et al.* 2017a). The

IUCN Red List of Species is well established globally and in South Africa and has formed a part of the NBA reporting since 2005 (Driver *et al.* 2005). The IUCN Red List of Ecosystems (RLE) is relatively new (v1.0 released in 2016), and prior to its development South Africa developed its own ecosystem Threat Status assessment framework between 2004 and 2008 (RSA 2011). The second indicator, Protection Level, was developed in South Africa for national reporting (Driver *et al.* 2004) and addresses the extent to which ecosystems and species are protected.

In the 2004 and 2011 national assessments Protection Level was only applied to ecosystems. Over the last two years SANBI's Threatened Species Unit has applied the indicator to species and it will be reported on for the first time in the NBA 2018. These headline indicators provide a way of comparing results meaningfully across the different realms, and also provide a standardised framework that links with policy and legislation in South Africa, thus facilitating the interface between science and policy. There is growing recognition within government and other institutions of this framework and the need to respond to these headline indicators in planning and decision making.

Ecosystem indicators

Ecosystem Threat Status tells us about the degree to which ecosystems are still intact or alternatively losing vital aspects of their structure, function and composition, on which their ability to provide ecosystem services ultimately depends (Figure 2). The conceptual 'end point' of decline for an ecosystem is termed 'collapse' and is equivalent to extinction in the species Red Listing framework. Ecosystem types are categorised as Critically Endangered (CR), Endangered (EN), Vulnerable (VU) or Least Concern (LC), based on the proportion of each ecosystem type that remains in good ecological condition relative to a series of thresholds.

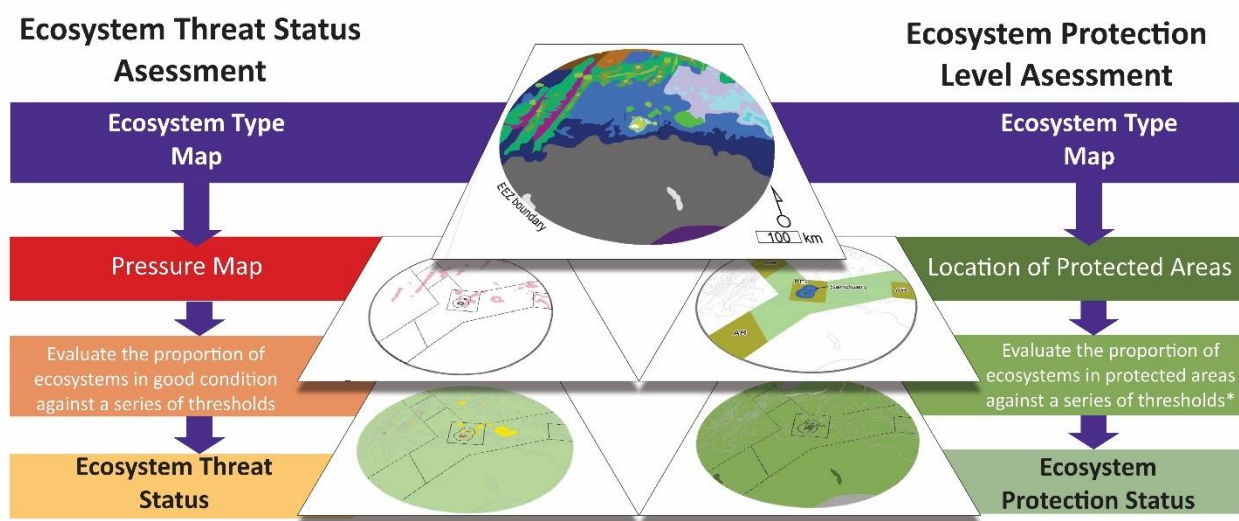


Figure 2. Steps in assessing Ecosystem Threat Status and Ecosystem Protection Level. Note the link between ecosystem condition and Protection Level – only natural habitat contributes to Protection Level targets (e.g. the airport within a large protected area would not contribute to protection targets as the natural habitat has been lost).

For the NBA 2018 the IUCN Red List of Ecosystems was used as the risk assessment framework for terrestrial ecosystems (Bland *et al.* 2017a). The previous National Biodiversity Assessments (2004 and 2011) predated the development of the IUCN RLE, and used the South African Threatened Ecosystem Framework (Driver *et al.* 2004, 2012, RSA 2011), making South Africa one of the pioneers globally of this approach to ecosystem assessment.

Ecosystem Protection Level tells us whether ecosystems are adequately protected or under-protected. Ecosystem types are categorised as Not Protected, Poorly Protected, Moderately Protected or Well Protected, based on the proportion of each ecosystem type that occurs within a protected area recognised in the National Environmental Management: Protected Areas Act (Act 57 of 2003)³. The ability to map and classify ecosystems into different ecosystem types is essential in order to assess Threat Status and Protection Levels and track trends over time. South Africa has an emerging national ecosystem classification system, including vegetation types, river ecosystem types, wetland ecosystem types, estuary ecosystem types, and marine and coastal ecosystem types, which provides an essential scientific basis for ecosystem-level monitoring, assessment and planning.

Species indicators

Threat Status of species tells us which species in South Africa are at risk of extinction. Threatened species are those with high risk of extinction and are classified in three categories of increasing risk of extinction Vulnerable (VU), Endangered (EN) and Critically Endangered (CR). Levels of threat are determined against quantitative threshold-based criteria. South Africa uses the latest version of the IUCN Red List Categories and Criteria, version 3.1. (IUCN 2012).

Protection level of species is presented for the first time in this NBA and has no global equivalent indicator. Protection level measures progress towards effective protection of a population persistence target for each species. The indicator consists of two components. The first measures how well represented each species is within the protected area network, based on the number of individuals of a species, or area of suitable habitat protected relative to the persistence target set for that species. This component allows for the identification of species which require further protection, where species which are not represented or are poorly represented within protected area network are prioritised for inclusion in spatial planning for protected area expansion. Component two includes a measure of how well a protected area is mitigating threats to each species and when combined with protected area representation provides an overall (effective) Protection Level measure for each species.

Both the Threat Status and Protection Status indicators for species allow South Africa to report against [Aichi Target 12](#) (Table 1) while the protection status also provides a measure of how well South Africa's protected areas are meeting the ecological representation requirement of [Aichi Target 11](#) (Table 1).

Table 1. Links between NBA headline indicators and Aichi Targets and SDGs

NBA indicator	Aichi Target	Sustainable Development Goal	Comment
Ecosystem Threat Status	5	15.1	This powerful indicator of threat to ecosystems is not adequately captured in Aichi and SDG related indicators.
Ecosystem Protection Level	11	15.1	A version of Protection Level is used in SDG 15.1 reporting.
Species Threat Status	12	15.5	Good links between national indicators and the Aichi and SDG indicators.
Species Protection Level	12	15.1	Not adequately captured in Aichi and SDG related indicators.
Ecosystem extent / habitat Loss	5	15.1, 6.6.1	Limited to forest and wetland extent in the SDGs.
Biological Invasion Indicators (species, Areas and Pathways)	9	15.8	Reasonable links between national indicators and Aichi and SDG indicators.

³ Hereafter referred to as the 'Protected Areas Act'.

Global biodiversity indicators

The Aichi Biodiversity Targets were structured around the CBDs 2011-2020 Strategic Plan for Biodiversity. Strategic Goals B (*Reduce the direct pressures on biodiversity and promote sustainable use*; Aichi Targets 5-10) and Goal C (*Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity*; Aichi Targets 11-13) are the most closely linked to the NBA 2018. Table 1 shows the links between the NBA headline indicators and the indicators for the Aichi Targets and Sustainable Development Goals. Ecosystem Threat Status, in particular, is not well captured in the Aichi Targets or SDGs. The SDGs linked to biodiversity propose Key Biodiversity Areas (KBAs) as a possible focal 'unit of assessment' for various indicators and it is likely that assessing the status of KBAs will become a global indicator of biodiversity that can be added to the NBA headline indicators. To facilitate this, SANBI has initiated a project in partnership with BirdLife South Africa and co-funded by the World Wide Fund for Nature (WWF) and Nedbank Green Trust to identify and delineate a preliminary KBA network for the South Africa based on the species and ecosystem information gathered in the NBA.

South Africa's sub-Antarctic territory

Location

The Prince Edward Islands (PEIs) are located in the Indian Ocean Sector of the Southern Ocean ($42^{\circ}45'S$ – $50^{\circ}45'S$, $32^{\circ}45'E$ – $43^{\circ}E$), approximately 1 700 km southeast of the mainland (Figure 3). The volcanic islands comprise of Prince Edward Island (45 km^2) and the larger Marion Island (270 km^2). The PEIs were formally declared and annexed in 1947 as part of the Union (now Republic) of South Africa under the Prince Edward Islands Act (No. 43 of 1948), making South Africa the only African country with territory in the sub-Antarctic. The territory extends 200 nautical miles from the islands and covers $474\,897 \text{ km}^2$, which supports unique terrestrial and marine biodiversity not found anywhere on the South African mainland or in its surrounding oceans (DEA 2013).

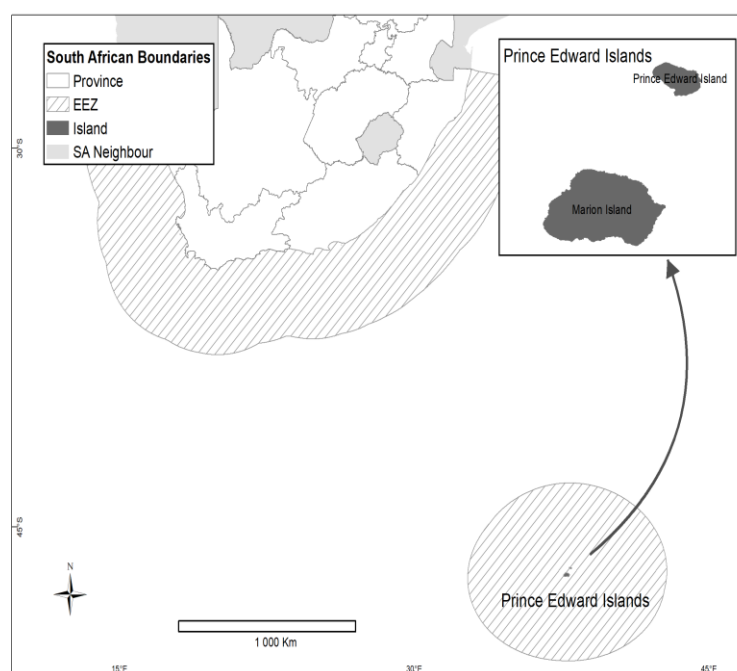


Figure 3. Map of the sub-Antarctic territory showing the location of the PEIs in relation to South Africa and the Exclusive Economic Zone (EEZ).

The sub-Antarctic territory includes major oceanic fronts associated with the Antarctic Circumpolar Current (ACC), the Sub-Antarctic Front (SAF) and the Antarctic Polar Front (APF). These fronts are extremely productive, strongly influencing ecological processes in the region and providing important foraging areas for top predators (Bost *et al.* 2009). The territory encompasses a wide range of geomorphological features, including seamounts, plateaus, abyssal plains and ridges, many of which enhance upwelling and productivity. The Southwest Indian Ridge (SWIR) is particularly important, as this global eddy hotspot drives the production of plankton-laden eddies towards the PEIs that provide food for a wide range of top predators (Durgadoo *et al.* 2010).

The PEIs are located on a shallow volcanic plateau that rises from 3000 m to breach the surface. Marion and Prince Edward Island reach 1230 m and 672 metres above sea level (m a.s.l.), respectively, and are separated by a 19 km shallow shelf. The islands emerged ~0.45 million years ago (mya) and have since been colonised by a wide range of sub-Antarctic flora and fauna. The dominant easterly-flowing current interacts with the plateau to form large phytoplankton blooms that enrich pelagic communities thousands of kilometres downstream. This is known as the *island mass effect* (Boden 1988). The plateau supports a rich seabed community of more than 500 species and is dominated by bryozoans and tube-building polychaetes (Von der Meden *et al.* 2017). The benthic shrimp *Nauticaris marionis* thrives here and provides an important food source for fish and seabirds. More than 30 fish species from 13 families occur at the islands, including the commercially important Patagonian Toothfish (*Dissostichus eleginoides*). Shallow parts of the plateau (< 20 m) are dominated by beds of Giant Kelp (*Macrocystis pyrifera*) and encrusting algae (*Lithothamnion* sp.), with the Bull Kelp (*Durvillaea antarctica*) occurring along cliff shorelines. These algal communities provide sheltered hunting areas for Killer Whales (*Orcinus orca*) that visit the islands in spring and summer.

The coastline is irregular and mostly comprised of young black lava in many forms, including steep cliff faces, sandy beaches, bays, inlets, and rocky and boulder shores (De Villiers 1976). The beaches and shores provide access to the many seals and penguins that breed at the islands. The seals include the Southern Elephant Seal (*Mirounga leonina*) which is listed as Near Threatened and two fur seals (Least Concern). There are 29 seabird species that breed at the islands – including penguins, albatrosses and petrels – of which 28 are listed as Threatened or Near Threatened. More than 40% of the global population of Wandering Albatrosses (*Diomedea exulans*) breed at the islands (Figure 4). The Crozet Shag (*Phalacrocorax melanogenis*) is the only seabird endemic to the PEIs and Crozet Islands, and the endemic Lesser Sheathbill (*Chionis minor*) is the only terrestrial bird (Ryan and Bester 2008).

The terrestrial vegetation occurs either within the unique sub-Antarctic Tundra or Polar Desert biomes that are not found on mainland South Africa. The cold and windy conditions prevent the survival of trees, with the only woody plant species being *Acaena magellanica*. The Kerguelen Cabbage (*Pringlea antiscorbutica*), endemic to the South Indian Ocean Province, of which the PEIs form part, is the only megaherb and occurs at the northern extent of its range at the PEIs. Many plants depend on the disturbance of and manuring by seals and seabirds, with some plant species such as *A. magellanica* and *Uncinia compacta* using seabirds to disperse their hooked seeds that attach to feathers. In total, there are 23 indigenous vascular plant species, 94 mosses and 46 liverworts, while 118 species of lichen have been identified (Gremmen and Smith 2008). The PEIs are classified as a Ramsar Wetland of International Importance due to their many freshwater lakes and peats. The terrestrial invertebrates at the islands include moths, spiders, weevils and springtails, many of which are endemic. Given the isolation and extreme weather conditions at the PEIs, most invertebrate species with flying ancestors have become flightless. Perhaps the most notable of these is the endemic Flightless Moth (*Pringleophaga marioni*) (Figure 5) which uses Wandering Albatross nests as an incubator during its caterpillar phase (Brent and Chown 2006). The unique biodiversity of the sub-Antarctic territory

makes it an incredible asset to South Africa and the world, and therefore deserves to be well managed and protected.



Figure 4. Some 3,650 pairs of Wandering Albatrosses *Diomedea exulans* breed at the PEIs, representing 40% of the world's population. Albatross Valley (pictured above) at Prince Edward Island supports the densest nesting area for wandering albatrosses on the planet. Photo: Peter Ryan.



Figure 5. The Flightless Moth (*Pringleophaga marioni*) is endemic to the PEIs. Photo: Otto Whitehead.

Benefits of South Africa's sub-Antarctic territory

South Africa's unique position in the sub-Antarctic provides novel benefits not available to other African countries. Benefits include a rich history of exploration, ecosystem services such as climate change mitigation and research in the sub-Antarctic, and indirect effects on ecotourism near the mainland. The region has potential for medical biodiscoveries (Olsen *et al.* 2016) with very little known about deeper-dwelling fauna.

The rich **history of exploration and research at the PEIs** has resulted in many globally important contributions by South Africans and created a strong scientific culture. The first collections of seabirds at the PEIs were recorded between 1830 and 1831, and the first marine observations were performed aboard the HMS *Challenger* in 1873, when deep-sea benthic specimens were sampled (Van Zinderen Bakker *et al.* 1971, Van Zinderen Bakker 1978). However, the formal South African scientific programme was initiated in 1965, with a group of scientists that included botanists, ornithologists, mammologist and geologists. The meteorological observations have occurred almost continuously since annexation in the 1940s that has increased the accuracy of weather predictions on the mainland, especially in the early years. Today there are a variety of programmes and organisations, such as the South African National Antarctic Programme (SANAP), that perform dedicated research in the Antarctic and sub-Antarctic (see DST's Marine and Antarctic Research Strategy). Several of these organisations have long running monitoring programs integral to monitoring patterns of change in these remote regions. These activities provide employment for many South African scientists and personnel.

A state of the art research station was completed at Marion Island in 2011 where 20 - 25 people live for 13 consecutive months doing research, maintaining the infrastructure and managing the Special Nature Reserve. A new research vessel, *The SA Agulhas II*, has been in operation since 2012 and is the principal gateway to the Antarctic. It allows scientific and logistical support to oceanographic scientists and research teams at Marion Island. All this investment has placed South Africa at the forefront of **Antarctic research** by providing continuous information and insights about terrestrial and marine environments in the sub-Antarctic. Given their unique position in the rapidly changing Southern Ocean, the islands and their surrounding ocean are important sentinels of climate change. Moreover, their relatively low human disturbance makes them great natural laboratories to study ecological processes (Ansorge *et al.* 2017).

Marine species provide untapped potential for South Africa's bio-economy through **biodiscovery**. Medicinal compounds have been found in several marine species, with some containing powerful compounds active against certain forms of cancer. For example, several marine sponges at the PEIs have been found to have cytotoxic activity against certain cancer cell lines (Olsen *et al.* 2016). It is estimated that more than 90% of novel chemicals from marine animals are undiscovered, and these may be worth \$563 billion - \$5.69 trillion (Erwin *et al.* 2010). South Africa's vast and little known sub-Antarctic territory therefore has significant potential to yield novel discoveries and provide medicines that further develop the economy.

The PEIs provide **critical breeding areas** for albatrosses and petrels that often feed in waters near mainland South Africa. The presence of these seabirds off the coast promotes boat-based ecotourism that benefits boat operators and their staff. No information is currently available to report on the numbers or benefits from these pelagic birding tours and such statistics would be useful in the future.

The most important benefit provided by the highly productive sub-Antarctic territory is most likely the role in **climate regulation**. Sub-Antarctic ecosystems play a significant role in carbon sequestration, providing an immensely valuable ecosystem service. The Southern Ocean absorbs 10% of annual global carbon emissions, directly mitigating the impacts of greenhouse gases on global climate change (Khaliwala *et al.* 2009). Biological activity in the surface waters converts carbon into organic matter that then sinks to the seafloor where it is stored.

Structure of this report

To successfully manage and conserve the unique and diverse biodiversity of the sub-Antarctic territory, appropriate systematic assessments of the state of marine and terrestrial ecosystems and species are needed. Firstly, these ecosystems are classified and mapped in Chapter 2, followed by an assessment of ecosystems in relation to existing pressures in Chapter 3. There were insufficient resources to fully assess the state of all species in the region but Box 2 in Chapter 3 provides a brief overview of the state of several important species that breed on the islands. The threats of alien invasive species and climate change are reviewed in Chapters 4 and 5. Key findings, recommended priority actions and key knowledge gaps are summarised in Chapter 6.

2. ECOSYSTEM CLASSIFICATION AND MAPPING

von der Meden, C., van der Merwe, S., Adams, R., Dayaram, A., Sink, K., Lombard, A., Bosman, A., Fourie, F., Harris, L., Hedding, D., Holness, S., Majiedt, P., Makhado, A., Meyer, R., Pistorius, P., Reisinger, R., Skowno, A., Somhlaba, S., Swart, S. and Smith, M. .2019. 'Chapter 2: Ecosystem classification and mapping', in *National Biodiversity Assessment 2018 Technical Report Volume 6: sub-Antarctic Territory*. Whitehead, T.O., Von der Meden, C., Skowno, A.L., Sink, K.L., van der Merwe, S., Adams, R. and Holness, S. (eds.). South African National Biodiversity Institute, Pretoria.



A waterfall at Van den Boogard river, Marion Island. Photo: Otto Whitehead.

Terrestrial ecosystem mapping

Introduction

The Prince Edward Islands (PEIs) have been classified and mapped into vegetation units⁴ based largely on floristics. The islands seem barren and species poor, but have 23 indigenous and 17 alien vascular plant species, as well as 134 non-vascular plant and 118 lichen species (Gremmen and Smith 2008). Plant communities on the PEIs fall into one of two biomes: Polar Desert or sub-Antarctic Tundra. These are grouped at a broad scale into six habitat complexes (Smith and Steenkamp 2001) or eight vegetation types (Smith and Mucina 2006), and at a finer scale have been grouped into 24 unique habitat types (Gremmen and Smith 2008). The harsh climate, together with biotic factors such as trampling and manuring, result in a complex mosaic of plant communities (Figure 6) that develop along gradients of nutrients, wind exposure, temperature and moisture (Gremmen and Smith 2008). Of the abiotic factors determining vegetation type distribution, soil moisture and exposure to wind are the most important, encompassing a gradient from wet-sheltered to dry-exposed habitats (Smith and Steenkamp 2001). Biotic factors, such as nutrient input by manuring or trampling also play a key role in determining the distribution of vegetation types (Smith and Steenkamp 2001). Geology or soil hydrology adds to the complexity and often forms communities with very different species compositions. For example, rainwater-influenced mires compared to groundwater-influenced mires form different plant communities (Gremmen 1981). Communities also change with altitude, forming dense communities dominated by vascular plants at lower altitudes, especially along the coast, to sparsely vegetated communities dominated by cryptogams and a single vascular plant species above 600 m above sea level (Gremmen and Smith 2008).



Figure 6. The complex mosaic of plant communities on Marion Island range from penguin-influenced vegetation in the foreground, to waterlogged mires in the midground, and the sparse wind-exposed cinder cone vegetation in the background. Photo: Stephni van der Merwe.

⁴ For this assessment, vegetation units are called vegetation types or ecosystem types (used interchangeably).

Ecosystem type classification

Huntley (1971) classified the vegetation on the islands into plant communities according to floristic composition and autecological characteristics of the dominant species, resulting in 13 plant communities, then called “noda”, grouped into five complexes based on the most important factors influencing their distribution. Gremmen (1981) expanded this classification with a phytosociological approach using floristic data combined with abiotic factors, resulting in 41 plant communities, grouped into 6 community complexes. Smith and Steenkamp (2001) then classified the plant communities on Marion Island using ordination and clustering methods based on the vegetation and soil chemistry, with six habitat complexes that now included the Polar Desert. After this, Smith and Mucina (2006) classified and described the vegetation at a broader spatial scale into eight vegetation types (Table 2) according to their distribution, important taxa, geology, soils, climate and landscape patterns based on the previous classifications. Lastly, Gremmen and Smith (2008) used a combination of the above classifications and descriptions to create a hybridized classification to describe the vegetation units, which they termed “habitats”, as ecological and soil conditions were also included together with floristics (Table 2). These habitats were also grouped into habitat complexes, which are equivalent or similar to the broad scale vegetation types classified by Smith and Mucina (2006).

Table 2. Terrestrial vegetation units on the Prince Edward Islands at different spatial scales, ranging from the fine scale “Habitat type”, to the broad scale “Vegetation type (map)”.

Vegetation type (map)	Vegetation type	Habitat complex	Habitat type
ST 1, 2 Sub-Antarctic Coastal Vegetation	ST 1 Sub-Antarctic Coastal Vegetation	Coastal Saltspray	Coastal Herbfield Habitat
			Coastal Fellfield Habitat
			Coastal Rock Habitat
			Saline Mires
	ST 2 Sub-Antarctic Biotic Herbfield and Grassland	Biotic	Coastal Tussock Grassland
			Cotula Herbfield
			Pedestalled Tussock Grassland
			Inland Tussock Grassland
			Biotic Mud Habitat
			Biotic Lawn Habitat
			Biotic Mire
ST 3,4,5 Sub-Antarctic Mire-Slope Vegetation	ST 3 Sub-Antarctic Mire	Mire	Wet Mire Habitat
			Mesic Mire Habitat
			Dry Mire Habitat
			Mire Drainage Line
	ST 4 Sub-Antarctic Drainage Line and Spring Vegetation	Slope	Slope Drainage Line and Streambank Habitat
			Dwarf Shrub Fernbrake Habitat
			Spring and Flush Habitat
	ST 5 Sub-Antarctic Fernbrake Vegetation	Slope	Open Fernbrake Habitat
			Closed Fernbrake Habitat
			Mesic Fernbrake Habitat
ST 6 Sub-Antarctic Fellfield	ST 6 Sub-Antarctic Fellfield	Fellfield	Xeric Fellfield Habitat
			Mesic Fellfield Habitat
ST 7 Sub-Antarctic Cinder Cone	ST 7 Sub-Antarctic Cinder Cone	Fellfield/Polar Desert	Xeric Fellfield Habitat
			Polar Desert
PD 1 Sub-Antarctic Polar Desert	PD 1 Sub-Antarctic Polar Desert	Polar Desert	Polar Desert

“Vegetation type (map)” (Figure 7) and “Vegetation type” were classified according to Smith and Mucina, (2006), whereas “Habitat complex” and “Habitat type” were classified according to Gremmen and Smith (2008).

For this assessment, vegetation units described by Smith and Mucina (2006) was used to group the vegetation (and associated biota) of the islands (Table 2) for a seamless integration with the ecosystem types of the other realms in the NBA, especially the terrestrial realm that uses the same vegetation map (the

National Vegetation Map) and spatial scale for the mainland. In this map (Figure 7), the PEIs have been mapped as five vegetation types (equivalent to ecosystem types) (Mucina and Rutherford 2006). The five vegetation types range from dense vegetation communities influenced by trampling and nutrient input by seabirds and seals, such as sub-Antarctic Biotic Herbfield and Grassland, to barren moss-dominated sub-Antarctic Polar Desert (Smith and Mucina 2006). The vegetation types would be equivalent to Gremmen and Smith's (2008) "habitat complexes", which are made up of multiple smaller habitat types (Table 2).

When the vegetation map was created, small scale variation of vegetation made it challenging to map vegetation types at a coarse scale and it was not feasible at the required finer scales to appropriately represent the complex mosaic (Smith & Mucina 2006). Vegetation types were therefore grouped into five types for mapping purposes (Figure 7) even though there were eight vegetation types described (Table 2). Sub-Antarctic Coastal Vegetation comprises two vegetation types (Table 2) and Sub-Antarctic Mire-Slope Vegetation comprises a mosaic of three vegetation types (Table 2; Smith and Mucina 2006). For the ecosystem assessments, five mapped vegetation types were considered with a description of the finer scale eight vegetation types listed below. Research is underway to disentangle the small scale mosaic of vegetation types, with the aim of mapping at a finer scale. AZm 2 Sub-Antarctic Kelp Beds, described as a vegetation type by Smith and Mucina (2006), was removed as a terrestrial vegetation type in 2012 and now forms part of the Marine Ecosystem Map (Dayaram *et al.* 2017).

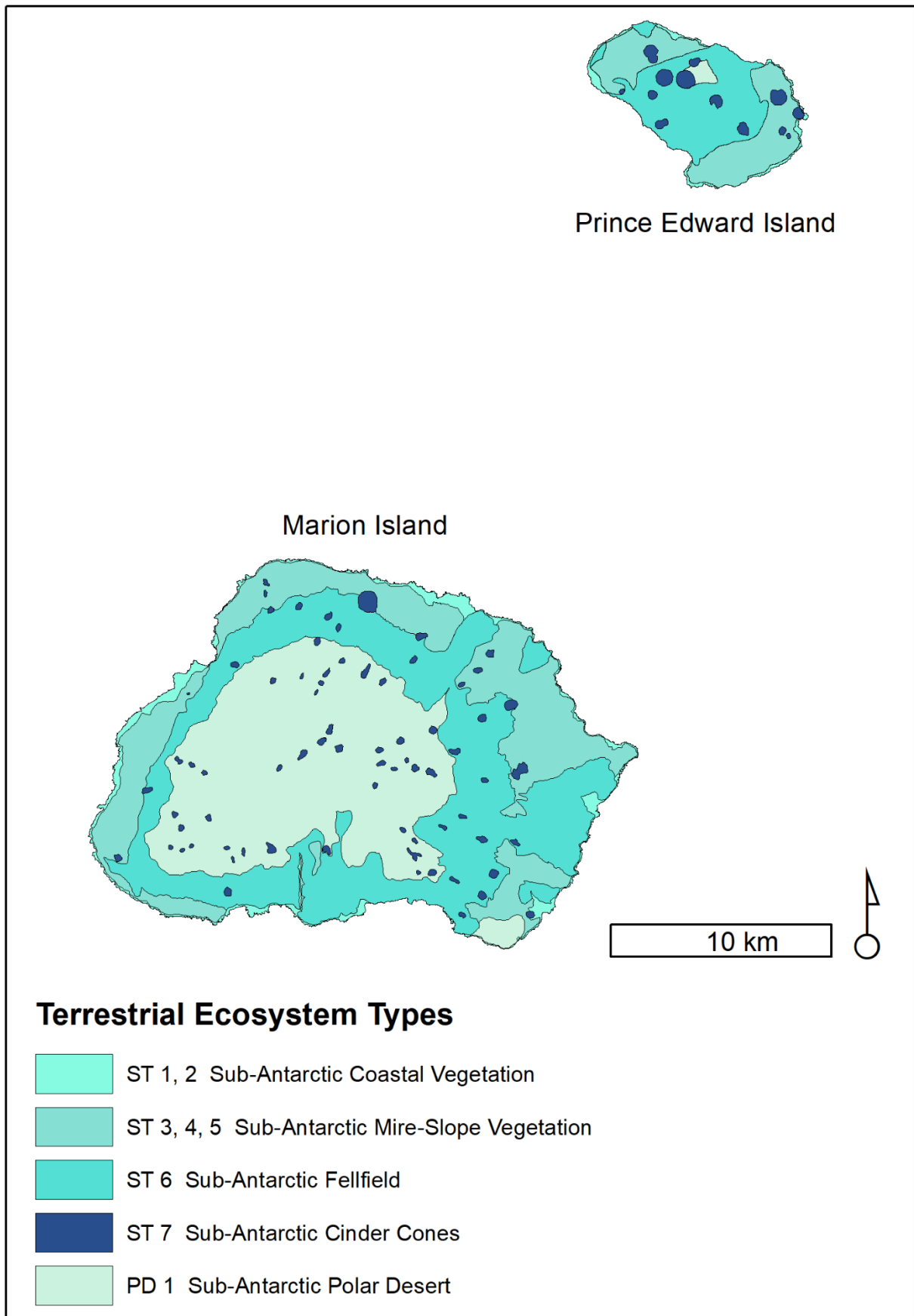


Figure 7. Terrestrial Ecosystem Map of the Prince Edward Islands (National Vegetation Map 2018).



Figure 8. Terrestrial vegetation types at the PEIs: ST 1: Sub-Antarctic Coastal Vegetation, ST 2: Sub-Antarctic Biotic Herbfield and Grassland, ST 3: Sub-Antarctic Mire-Slope Vegetation, ST 4: Sub-Antarctic Drainage Line and Spring Vegetation, ST 5: Sub-Antarctic Fernbrake Vegetation, ST 6: Sub-Antarctic Fellfield Vegetation, ST 7: Sub-Antarctic Cinder Cone Vegetation and PD 1: Polar Desert.

Ecosystem type descriptions

Sub-Antarctic Coastal Vegetation (ST 1 & 2)

Alternative classifications: Salt Spray Complex (Huntley 1971). 4.1. *Crassula moschata* Complex (Gremmen, 1981). Coastal Salt-spray Complex (Smith and Steenkamp 2001, Smith *et al.* 2001). Biotic Complex (Huntley 1971). 4.2. *Callitriche antarctica*–*Poa cookii* Complex (Gremmen 1981). 4. Biotic Grassland Complex and 5. Biotic Herbfield Complex (Smith and Steenkamp 2001, Smith *et al.* 2001). Subantarctic Coastal Vegetation and – Biotic Herbfield and Grassland (Smith and Mucina 2006). Coastal Saltspray Complex and Biotic Complex (Gremmen and Smith 2008).

This mapping unit is made up of *ST 1 Sub-Antarctic Coastal Vegetation* and *ST 2 Sub-Antarctic Biotic Herbfield and Grassland* and occurs in coastal areas around both islands.

ST 1 Sub-Antarctic Coastal Vegetation

This vegetation type occurs mainly on black lava flows within 50 m of the coast in the east, but extends further inland on the North, South and West coasts in areas subjected to salt spray or occasional inundation by waves. Soils are mostly black or dark brown, fibrous and saline peats. This vegetation type experiences an oceanic climate due to its location near the coast and low altitude, with little diurnal and seasonal variation. It consists of herbfields dominated by *Crassula moschata* or *Cotula plumosa* (Figure 9) and may co-dominate with *Azorella selago* at very exposed sites. Bryophytes and liverworts, particularly *Clasmatocolea vermicularis*, may also be important taxa. Birds, particularly Rockhopper Penguins (*Eudyptes chrysocome*), and fur seals may also influence the vegetation through manuring and trampling.

References: Huntley (1971); Gremmen (1981); Smith and Steenkamp (2001); Smith *et al.* (2001); Smith and Mucina (2006); Gremmen and Smith (2008).



Figure 9. Sub-Antarctic Coastal Vegetation consisting of herbfields dominated by *Crassula moschata* (bottom centre), with patches of *Cotula plumosa* (bottom left corner). Photo: Stephni van der Merwe.

ST 2 Sub-Antarctic Biotic Herbfield and Grassland

This vegetation type occurs in coastal areas influenced by trampling and manuring by seals and seabirds, and around bird colonies or nests further inland. Soils are mostly peat, containing high amounts of organic and inorganic nitrogen and phosphorus, being bare at highly trampled sites, but may form an organic mud where both trampling and manuring are severe. This vegetation type experiences an oceanic climate with little diurnal and seasonal variation due to its location near the coast and at low altitudes. *Callitriche antarctica*, *C. plumosa*, *Montia fontana*, *Sagina procumbens*⁵ are the dominant herbs, along with the graminoids *Agrostis stolonifera*², *Poa annua*² and *Poa cookii* (Figure 10). The moss *Brachythecium rutabulum* and the liverwort *C.*

² Alien invasive plant species.

vermicularis may also be dominant. The biotic disturbance along with nutrient enrichment creates ideal conditions for alien plant species and also attracts mice, which are common in this vegetation type.

References: Huntley (1971); Gremmen (1981); Smith and Steenkamp (2001); Smith *et al.* (2001); Smith and Mucina (2006); Gremmen and Smith (2008).



Figure 10. A Sub-Antarctic Fur Seal lies on a *P. cookii* pedestalled tussock grass with the invasive *P. annua* on the far right, showcasing Sub-Antarctic Biotic Herbfield and Grassland. Photo: Stephni van der Merwe.

Sub-Antarctic Mire-Slope Vegetation (ST 3, 4 and 5)

Alternative classifications: Swamp Complex p.p. (Huntley 1971). 4.4. *Juncus scheuchzerioides*–*Blepharidophyllum densifolium* Complex (Gremmen 1981). 6. Mire Complex (Smith and Steenkamp 2001; Smith *et al.* 2001). Swamp Complex p.p. (Huntley 1971). 4.3. *Acaena magellanica*–*Brachythecium* Complex (Gremmen 1981). 3. Slope Complex p.p., incl. 3.5. Slope Drainage Line and Streambank Habitat and 3.6. Spring and Flush Habitat (Smith and Steenkamp 2001; Smith *et al.* 2001). Slope Complex (Huntley 1971). 4.5. *Blechnum penna-marina* Complex (Gremmen 1981). 3. Slope Complex p.p. (incl. Habitats 3.1 to 3.4) (Smith and Steenkamp 2001; Smith *et al.* 2001). Subantarctic mire, – Drainage Line and Spring Vegetation and - Fernbrake Vegetation (Smith and Mucina, 2006). Mire Complex and Slope Complex (Gremmen and Smith 2008).

This vegetation type is mapped as one unit, but is made up of *ST 3 Sub-Antarctic Mire*, *ST 4 Sub-Antarctic Drainage Line and Spring Vegetation* and *ST 5 Sub-Antarctic Fernbrake Vegetation*. These units occur in an intricate small-scale mosaic of mire, fernbrake, drainage line and fellfield vegetation. It is characterised by mires, generally in the lowlands, as well as low and mid altitude slopes that are covered by dense vegetation. In the mires, graminoids generally form a canopy over the dominant bryophyte layer. Here, high soil moisture with organic peats prevail. The slopes form dense mats of vegetation and also contain organic soils, however these soils are well-drained. In the slope vegetation, biotic impacts and saltspray are negligible.

ST 3 Sub-Antarctic Mire

Mire vegetation occurs in flat or slightly sloping lowland areas around the islands, especially below 200 m a.s.l. and up to 400 m a.s.l. Soils are generally waterlogged peats up to 2.5 m deep, which are highly organic and occur on grey and black lava flows. The mires can be considered ombrotrophic – dependent on atmospheric moisture for nutrients – because when rainwater leaches downward, it leaves the surface soils where vegetation grows acidic and does not mix back up from the mineral-rich soils below where lateral movement of water occurs. The top 1-2 cm freezes frequently in autumn, winter and spring. In flat or slightly sloping areas the graminoids *Agrostis magellanica*, *Juncus scheuchzerioides* and *Uncinia compacta* are dominant (Figure 11), with an abundant bryophyte flora (about 60 species). The dominant herb is *Ranunculus bitermatus*, although many others may also occur in mires. In wetter areas, the dominating liverworts and mosses include *Blepharidophyllum densifolium*, *Clasmotocolea humilis*, *Sanionia uncinata* and

Distichophyllum fasciculatum. In drier mires *Jamesoniella colorata* and *Racomitrium lanuginosum* are abundant and the fern *Blechnum penna-marina* may also occur.

References: Huntley (1971); Gremmen (1981); Smith and Steenkamp (2001), Smith *et al.* (2001); Smith and Mucina (2006); Gremmen and Smith (2008).



Figure 11. Mires on the west coast of the island with bryophytes and grasses visible. Photo: Stephni van der Merwe.

ST 4 Sub-Antarctic Drainage Line and Spring Vegetation

This vegetation type occurs on slopes with impeded drainage (Figure 12), along drainage lines and in sheltered depressions up to 400 m a.s.l., more commonly on younger black lava with wet peat, sometimes with volcanish ash. Complete plant cover, dominated by the suffrutex *Acaena magellanica* and mosses such as *B. rutabulum*, *Brachythecium subplicatum* and *S. uncinata*. *P. cookii*, *A. stolonifera*⁶ grasses may also be dominant.

References: Huntley (1971); Gremmen (1981); Smith and Steenkamp (2001); Smith *et al.* (2001); Smith and Mucina (2006); Gremmen and Smith (2008).



Figure 12. Sub-Antarctic Drainage Line and Spring Vegetation dominated by the only woody plant species *Acaena magellanica* (shown here with seed heads). Photo: Otto Whitehead.

⁶ Alien invasive species.

ST 5 Sub-Antarctic Fernbrake Vegetation

This vegetation is widespread on the PEIs. It occurs up to 200 m a.s.l., occupying ~34% of Marion Island, mainly on black lava and rarely on grey lava. The soils in Fernbrake Vegetation are the best developed on the islands. Most communities in Fernbrake are dominated by the fern (*Blechnum penna-marina*) (Figure 13), with closed fernbrake covered in thick carpets of this fern being the climax vegetation on slopes. However, *Azorella selago* and cushion-forming mosses may be co-dominant in more exposed sites, whereas on less steep slopes graminoids *U. compacta*, *P. cookii* and *Agrostis magellanica*, as well as bryophytes *Jamesoniella colorata* and *Racomitrium lanuginosum* may also be abundant. At night the closed vegetation cover insulates the soil from heat loss, leading to low variation in daily temperatures. The ferns *Elaphoglossum randii* and *Polystichum marionense*, and the liverwort (*Symphyogyna marionensis*), occur in this vegetation type and are endemic to the Kerguelen Floristic Province, which includes the PEIs.

References: Huntley (1971); Gremmen (1981); Smith and Steenkamp (2001); Smith *et al.* (2001); Smith and Mucina (2006); Gremmen and Smith (2008).



Figure 13. Dense stands of *Blechnum penna-marina* in Sub-Antarctic Fernbrake Vegetation. Photo: Stephni van der Merwe.

Sub-Antarctic Fellfield (ST 6)

Alternative classifications: Wind Desert Complex p.p. (incl. *Azorella selago* fjaeldmark) (Huntley 1971). 4.6. *Andreaea-Racomitrium crispulum* Complex (Gremmen 1981). 2. Fellfield Complex (Smith and Steenkamp, 2001; Smith *et al.* 2001). Subantarctic Fellfield (Smith and Mucina 2006). Fellfield Complex (Gremmen and Smith 2008).

Fellfield is the dominant vegetation type on the PEIs between 200 and 500 m a.s.l., but also occurs at lower altitudes, occupying ~46% of the surface area of Marion Island. Fellfield occurs on exposed rocky ridges (Figure 14) on both black and grey lava (but more commonly on older grey lava) and in soils that have more mineral content compared to other vegetation types. Soils are usually shallow, but may be deeper when organic matter derived from *A. selago* and/or volcanic ash is present. Sparse vegetation cover and exposure to wind subjects the soils to frequent freeze-thaw cycles. Fellfield vegetation cover varies from 5 to 50%, with the cushion-forming *A. selago* being dominant, together with other ball and cushion-forming mosses. *Agrostis magellanica* is the most common graminoid and grows epithetically on the cushion plants, and often co-dominates with *A. selago* at lower altitudes. Species richness may be high due to the prevalence of varied microhabitats. The moss *Valdonia microcarpa* and herb *Colobanthus kerguelensis* that commonly occur in Fellfield are endemic to the Kerguelen Floristic Province.

References: Huntley (1971); Gremmen (1981); Smith *et al.* (2001); le Roux and McGeoch (2004); le Roux *et al.* (2005); Smith and Mucina (2006); Gremmen and Smith (2008).



Figure 14. Sub-Antarctic Fellfield vegetation with *Agrostis magellanica* grasses growing within the cushion plant *Azorella selago*. Photo: Stephni van der Merwe.

Sub-Antarctic Cinder Cone Vegetation (ST 7)

Alternative classifications: Wind Desert Complex p.p. (incl. *Azorella selago* fjaeldmark) (Huntley 1971). 4.6. *Andreaea-Racomitrium crispulum* Complex (Gremmen 1981). 2. Fellfield Complex (Smith and Steenkamp 2001; Smith *et al.* 2001). Subantarctic Cinder Cone (Smith and Mucina 2006). Fellfield and Polar Desert Complex (Gremmen and Smith 2008).

Cinder cones are prominent features on the PEIs and are characterised by Holocene cones of red volcanic ash resulting from historical eruptions of young black lava (Figure 15). The scoria comprises of loose vesicular fragments but in some places has been welded into more stable substrate. Most cinder cones have sparse or no vegetation, but at lower altitudes the vegetation is similar to Fellfield, being dominated by *A. selago* cushions and some other vascular species, particularly *Agrostis magellanica*. At higher altitudes, vascular plants cannot survive and here cinder cones are dominated by bryophytes and lichens, resembling the Polar Desert.

References: Gremmen (1981); le Roux and McGeoch (2004); Smith and Mucina (2006).



Figure 15. Sub-Antarctic Cinder Cone Vegetation at low altitude, with *Azorella selago* cushion plants growing on the red scoria of a cinder cone. Photo: Stephni van der Merwe.

Sub-Antarctic Polar Desert (PD 1)

Alternative classifications: Wind Desert Complex p.p. (incl. *Azorella selago* fjaeldmark) (Huntley 1971). Subantarctic Polar Desert (Smith and Mucina 2006). Polar Desert Complex (Gremmen and Smith 2008).

The Polar Desert is a barren vegetation type dominated by physical processes and an absence of soils, occurring on loose pebble-sized scoria deposits and occasional rocks or boulders on the surface (Figure 16). It is characterised by sparse communities of bryophytes and lichens, with a lack of vascular plants, except *A. selago*, the dominant vascular plant on the islands. Only bryophytes and lichens are able to survive in this harsh environment, and most lichens have not been identified. In more sheltered depressions the moss *Ditrichum strictum* dominates. On certain slopes, bryophytes occur beneath rocks where they are sheltered from the harsh weather.

References: Huntley (1971); Gremmen (1981); Smith & Steenkamp (2001); Smith *et al.* (2001); Smith & Mucina (2006); Gremmen & Smith (2008).



Figure 16. Polar Desert vegetation is characterised by an absence of soil and lack of vascular plants, however lichens and bryophytes are still able to survive this harsh environment. Photo: Otto Whitehead.

Marine ecosystem classification and mapping

The 2018 Prince Edward Island marine ecosystem classification and map enabled the first wall-to-wall map for South Africa's sub-Antarctic territory. Building on the map of 5 terrestrial ecosystem types, a total of 29 marine ecosystem types were identified. These encompass both coastal and deep sea marine ecosystem types ranging from the upper-shore limit of the salt-spray influenced supralittoral zone at the islands to the 200 nautical mile limit of the Exclusive Economic Zone (EEZ). The classification broadly followed the hierarchical framework of the mainland marine classification, and that of existing circumpolar 'ecoregionalisations' of the Southern Ocean. By tailoring the map to the spatial scale, availability of data and biophysical processes relevant within the territory, it captures key biophysical processes and biodiversity patterns that characterise the marine ecosystems at a practical scale and level of detail. Many of the core processes and patterns were initially recognised by (Lombard *et al.* 2007) and this chapter expanded on this work using recent regional classifications and new spatial layers.

Introduction

Knowledge of South Africa's sub-Antarctic marine ecosystems benefit from a long history of research extending back to the Challenger (1873) and Discovery II (1935) expeditions. More recently, conservation planning efforts at the islands resulted in the design and proclamation of South Africa's first offshore MPA in 2013 (Lombard *et al.* 2007, DEA 2013). Although South Africa's mainland marine ecosystems have been included in two spatial National Biodiversity Assessments (Lombard *et al.* 2004, Sink *et al.* 2012), the sub-Antarctic territory was not integrated. The need to include the territory in the National Biodiversity Assessment (NBA) has, however, been recognised (Driver *et al.* 2005, Sink *et al.* 2012).

The inaccessibility, expense and technological challenges associated with classifying and mapping ocean territories present many challenges. These are amplified by the remoteness and extreme nature of the sub-Antarctic, where data are often limited by seasonality of access and inaccessibility due to extreme environmental conditions. Fortunately, these challenges are partially overcome through the use of remotely sensed, modelled and opportunistic sources of data. Drawing on all available data, this chapter presents the first ecosystem classification and map created for South Africa's sub-Antarctic territory. The process involved an expert-driven, data informed approach. Implementation was achieved by bringing together existing regional spatial layers and additional local data. An expert workshop with 25 participants was convened by SANBI in August 2017 to guide the approach taken in the classification and mapping efforts (Appendix A). Following development of the initial classification, the proposed methods and outputs were presented at the Marine Ecosystem Committee Meetings in August and November 2017. This chapter describes the structure of the classification, the rationale and input data behind each of its levels, and the mapping process itself.

Key differences to the mainland marine classification include a simplified classification of shore types, without a backshore-foreshore distinction and estuarine components since the latter are not present at the PEI. Likewise, with little direct data on subtidal benthic substratum types, existing spatial layers for global and Antarctic seafloor geomorphology were used as a proxy for seabed type on the shelf, its slope and in the deep ocean. The identification of biogeographic patterns was based on existing regional (Southern Ocean scale) benthic and pelagic ecoregionalisations (Raymond 2011, Douglass *et al.* 2014). Refinements to these were made using local long-term data for ocean frontal positions and the local boundaries of the only known major geomorphological barrier, the South West Indian Ridge (SWIR). This approach delineated merged 'benthic-pelagic' ecoregions relevant to the sub-Antarctic territory (similar to Sink *et al.* 2019) so that single ecoregions included both benthic and pelagic components.

Classification approach

Development of the marine ecosystem classification for the sub-Antarctic territory was initiated with a review of ecosystem classifications of the marine realm, particularly in the Southern Ocean. Aligning with global benthic and pelagic classification methodology (Last *et al.* 2010, Raymond 2011, Douglass *et al.* 2014, Koubbi *et al.* 2016a, 2016b, Proud *et al.* 2017) and the mainland marine classification, a hierarchical framework was proposed and accepted at a dedicated marine ecosystem classification workshop convened by SANBI in August 2017 (Appendix A).

Marine ecosystems were classified according to four key drivers of biodiversity patterns (Figure 17). Regional circumpolar biogeography (ecoregion) was the broadest spatial classifier, defined by major ocean fronts, biological data and abiotic surrogates of biodiversity. Nested within ecoregion, depth (bathome) was the primary driver of biodiversity patterns, being an established surrogate for major ecological transitions (Howell 2010, Last *et al.* 2010, Rex and Etter 2010). Bathomes were subclassified according to seafloor geomorphology and associated substratum characteristics (Beaman and Harris 2005, O'Brien *et al.* 2009, Harris and Baker 2012, Koubbi *et al.* 2012). No further sub-classification was deemed necessary in the sub-Antarctic although finer-scale regional and depth patterns, other features and drivers of biodiversity pattern specific to broad ecosystem types was used in the mainland ocean territory.

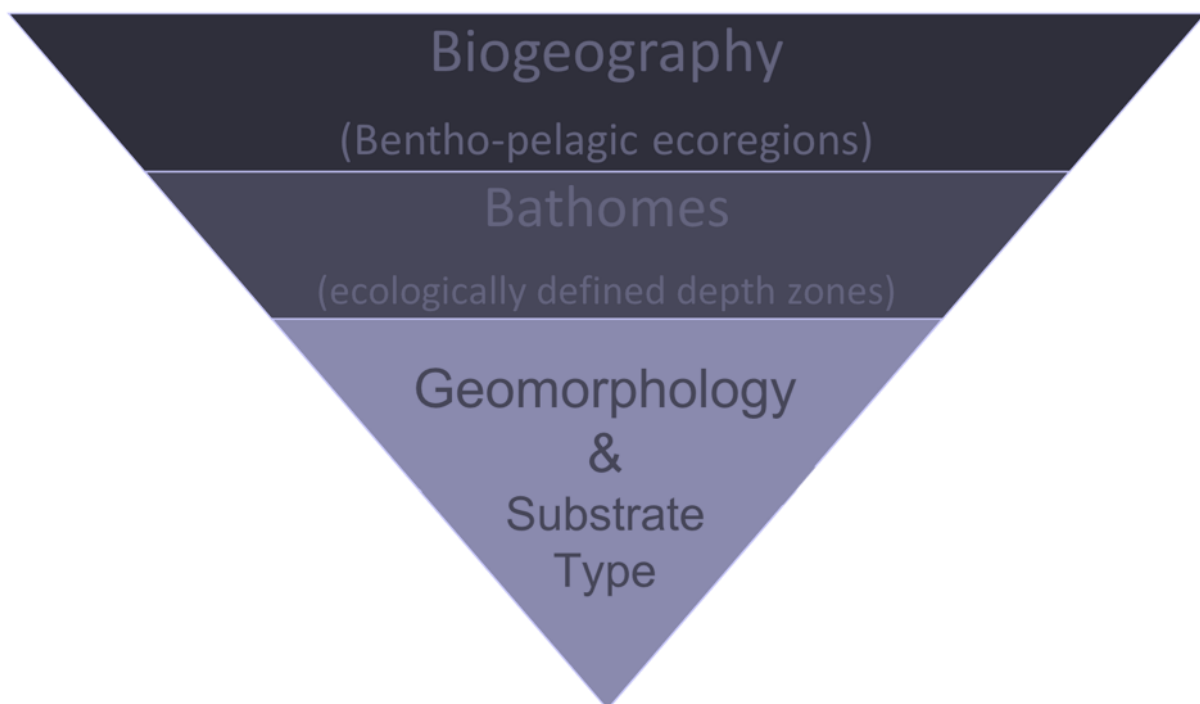


Figure 17. Diagrammatic representation of the hierarchical structure of South Africa's sub-Antarctic Marine Ecosystem Classification and Map.

The **first level** of classification was defined by four benthic-pelagic ecoregions: PEI Temperate, PEI Sub-Antarctic, PEI Polar Front and Ob and Lena Polar Front. These were based on existing benthic and pelagic ecoregions (Raymond 2011, Douglass *et al.* 2014) and long-term positions of major ocean fronts within the sub-Antarctic territory (Swart *et al.* 2010) – Sub-Antarctic (SAF) and Polar Fronts (PF) – to ensure that regionally established biogeographic patterns were incorporated. The **second level** of classification relied on

the delineation of ecologically defined bathomes according to bathymetric zones: shore, inner shelf, outer shelf, shelf edge, upper slope, mid slope, lower slope and the abyss. The combination of ecoregions and bathomes can be considered as bathyregions as in the classification in the mainland marine realm. Within each bathyregion, seafloor geomorphological features formed the **third level**, which included seamount, plateau, plateau slope, spreading/seamount ridge, abyssal plain, and rift valley and troughs. The **fourth level** of classification was based on the dominant substratum type associated with each geomorphological feature: hard, soft or mixed substrate. As such, these categorisations did not subclassify the geomorphological features since the features themselves are the surrogate for respective substratum types, they simply describe the likely substratum in each case. Shore types were based on a combination of the shore form (geomorphology), substratum type and wave exposure. Three additional spatial layers were included to enhance the description of ecosystem types; kelp coverage (*Macrocystis pyrifera*), important foraging areas for top predators and records of benthic Vulnerable Marine Ecosystem (VME) indicator taxa.

Rationale, input data and mapping methods

This first attempt at mapping South Africa's sub-Antarctic marine ecosystems was based on existing spatial layers for the region. Adjustments were made to regional layers by applying local data and a set of expert-driven rules. The most trusted, recent or relevant layers were dominant, with other layers merged to primary boundaries where necessary. For each element of the classification, mapping rules were established to deal with naming discrepancies, duplicates and competing interactions between elements. Isolated ecosystem types, particularly those covering only limited spatial extents, were evaluated in terms of their ecological validity, and if deemed invalid, were merged with broader types. Seven spatial layers formed the basis of the mapping exercise, although three others were generated and used descriptively without informing the delineations of the marine ecosystem map although providing additional information relevant to their description (Table 3). The rationale, input data and mapping process detailed below show how the theoretical classification was implemented.

Table 3. Data and layer sources used to construct the Marine Ecosystem Map for the sub-Antarctic territory. Additional descriptive layer sources are shaded.

Data layer	Source and/or contributor
Southern Ocean Benthic Classification	Based on (Douglass <i>et al.</i> 2014); <i>metadata</i> (https://data.aad.gov.au/metadata/records/SOBC).
Southern Ocean Pelagic bioregions	Based on (Raymond 2011).
Offshore Bathymetry	GEBCO_14 Grid, 30 arc-second resolution, version 20141103, http://www.gebco.net .
Shelf bathymetry	50m contour of soundings by South African Navy contributed by A. Kampfer (hydrographer, South African Navy).
Antarctic seafloor geomorphology	Based on O'Brien <i>et al.</i> 2009 with supporting information from Douglass <i>et al.</i> 2014.
Global seafloor geomorphology	Based on Harris <i>et al.</i> (2014). Available online: http://www.bluehabitats.org/?page_id=58
Ocean fronts	Created by Dr S. Swart (University of Gothenburg).
Vulnerable Marine Ecosystems (VME)	Compiled by Dr C. von der Meden (SANBI) based on the following sources: CCAMLR fishery observer VME records, DAFF research trawl data notes of R. Leslie, GBIF: SOMBASE_Bioconstructors.
Kelp	Created by R. Meyer (CSIR, Pretoria) and F. Fourie (Sea Technology Services, Cape Town).
Top predator habitats	PEI scale layers created by R. Reisinger (CNRS, Paris) based on (Reisinger <i>et al.</i> 2018).

Ecoregions

The importance of biogeographic variation is well established and is particularly relevant in the Southern Ocean where large-scale processes and features play a significant role in creating ecological patterns and variations in ecosystems (Griffiths *et al.* 2009, Proud *et al.* 2017). Existing biogeographic classifications for

the Southern Ocean identify benthic 'Ecoregions' (Douglass *et al.* 2014) and pelagic 'Bioregions' (Raymond 2011). Following the hybrid approach of Koubbi *et al.* (2012), the Southern Ocean Benthic Classification (SOBC) of Douglass *et al.* (2014) was evaluated in relation to the pelagic bioregionalisation of Raymond (2011). The 23 SOBC ecoregions are based on a comprehensive set of biotic and abiotic data including bathymetry, geomorphology, seabed temperatures, and benthic species distributions and endemism. The sub-Antarctic territory intersects three large benthic ecoregions: Del Cano, Atlantic Basin, and Ob and Lena.

Pelagic regionalisation by Raymond (2011) identified 20 circumpolar pelagic bioregions using sea surface temperature, depth and sea ice cover. Six are represented within South Africa's sub-Antarctic territory, of which three are driven by large-scale oceanographic divisions between Temperate, Sub-Antarctic and Antarctic waters. The close alignment of benthic and pelagic divisions resulted in the delineation of four composite benthic-pelagic ecoregions (see Table 4). The boundaries of each ecoregion were delineated using the intersections between long-term average positions of the SAF and APF and the South West Indian Ridge (SWIR). The ecological importance of the fronts and the ridge are well known, particularly in terms of patterns of primary productivity and alignment with top predator foraging areas (Nel *et al.* 2001, Reisinger *et al.* 2018).

The SOBC layer was used as a foundational layer for the map of sub-Antarctic marine ecosystems, which is a biophysical dataset with a spatial resolution of ca. 10 km (Douglass *et al.* 2014). The original Del Cano benthic ecoregion was split into Temperate and Sub-Antarctic components based on the mean position of the SAF and northern limit of the APF. However, where the SWIR extended north of the SAF, the northern edge of the SWIR was used (see Figure 18). This included a narrow panhandle-shaped extension of the SWIR on the northeastern side of the territory. The area south of the sub-Antarctic component was classified as the PEI Polar Front Ecoregion, following the southern boundary of the SOBC's Atlantic Basin ecoregion. The Ob and Lena Polar Front Ecoregion was defined as the small area of the Ob and Lena benthic ecoregion that intersects the South Africa's sub-Antarctic territory (Figure 18).

Table 4. The PEI combined benthic-pelagic ecoregions developed based on integration of the Southern Ocean Benthic Classification (SOBC) ecoregions (Douglass *et al.* 2014) and pelagic classification bioregions (Raymond 2011).

SOBC ecoregions	SOBC Description	SO pelagic bioregions	PEI benthic-pelagic ecoregions	PEI description
Del Cano	Shallow, warmer seabed within the sub-Antarctic zone including parts of the South West Indian Ridge seamounts, the Del Cano Rise and the Prince Edward Islands.	Temperate	PEI Temperate	Warmer, north of SAF and SWIR boundary.
		Sub-Antarctic	PEI Sub-Antarctic	Shallow, heterogeneous geomorphology between SAF and APF, Includes SWIR seamounts, PEI.
Atlantic Basin	The very deep and very cold rugose ocean floor and abyssal plain of the South Atlantic Ocean Basin and Weddell Sea.	Antarctic Polar Front	PEI Polar Front	Deep, cold areas, geomorphologically homogeneous and abyssal south of APF.
Ob and Lena	Shallow, warm seabed in the Polar Frontal zone, including the Ob and Lena banks and the seamounts to their east.	Antarctic Polar Front	Ob and Lena Polar Front	Extreme limit of Ob and Lena ecoregion south of APF.

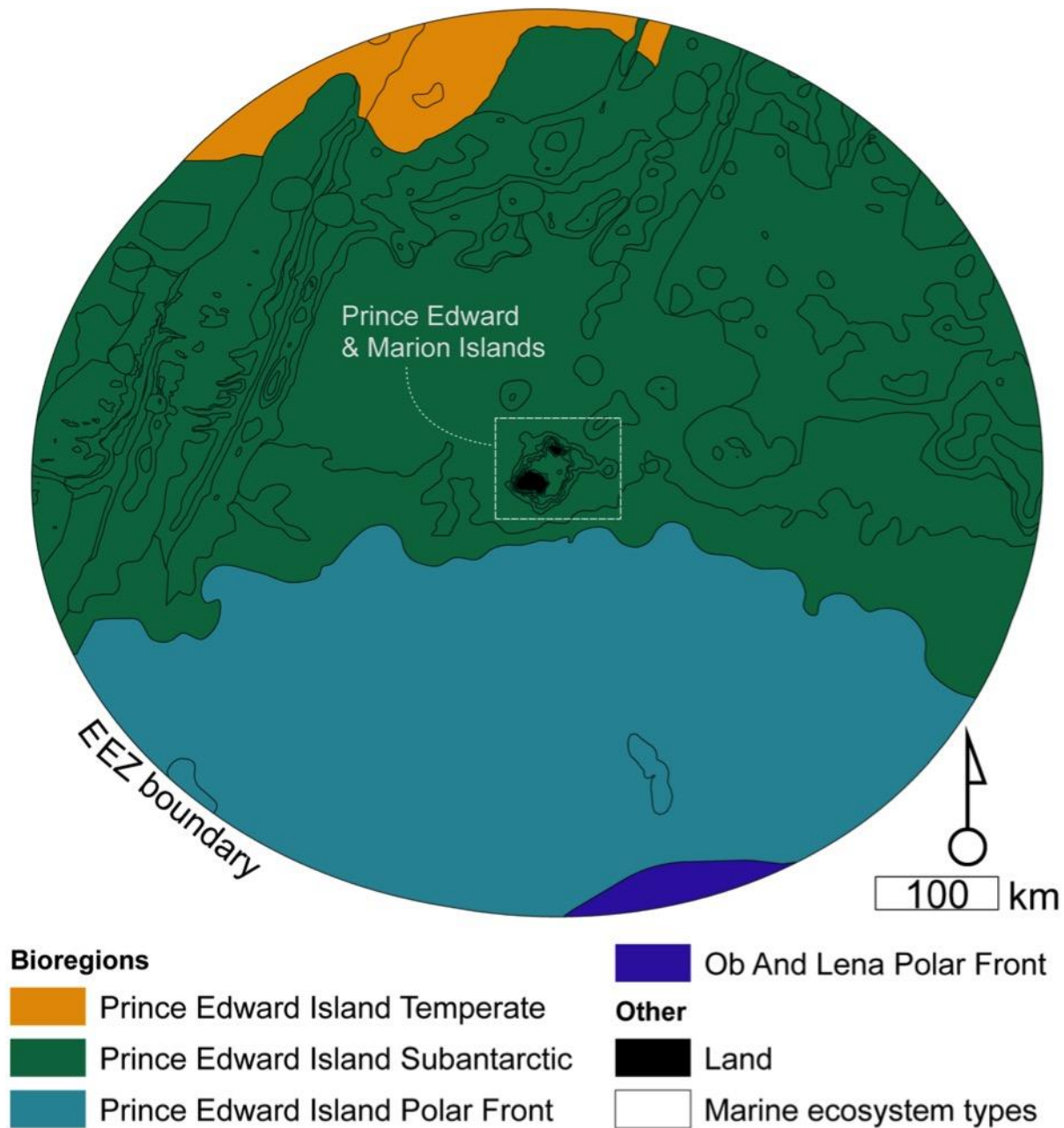


Figure 18. Four ecologically defined, benthic-pelagic biogeographic units called ecoregions were identified.

Bathomes

Across-shelf topography and depth are useful proxies for patterns of biodiversity and biological zonation (Diaz *et al.* 2004, Last *et al.* 2010, Ramirez-Llodra *et al.* 2010). This is largely because they correlate with major environmental drivers of physical gradients, including those of light, temperature, oxygen, water column mixing, currents, nutrient flux and food supply rates to the benthos (Howell 2010, Rex and Etter 2010). As such, topography and depth have been used as primary classifiers in ecosystem classifications, bioregionalisation studies and marine spatial planning in the Southern Ocean (Lombard *et al.* 2007, Koubbi *et al.* 2012, Douglass *et al.* 2014, Trathan *et al.* 2014). Like the mainland classification, the marine realm was considered from marine-influenced shores at the PEIs to abyssal depths. The islands' shore ecosystems were classified into four types based on published descriptions and intertidal surveys (De Villiers 1976, Blankley and Grindley 1985). For subtidal areas, a high-level distinction was made using the shelf edge to delineate

neritic (shelf) and oceanic (deep ocean) zones. Depth related patterns in benthic fauna on the island shelf were categorised based on local benthic surveys (Branch *et al.* 1993, Von der Meden *et al.* 2017) and deeper patterns were based on broader multi-taxon distributions (Table 5, Table 7).

Table 5. Summary of established bathomes and depth breaks for the PEI shelf based on *in situ* benthic ecological patterns in Branch *et al.* (1993) and von der Meden *et al.* (2017). Deep-sea depth breaks were defined according to regional patterns established by Brandt *et al.* (2009) and Douglass *et al.* (2014).

	PEI depth breaks	Key ecological patterns
Branch <i>et al.</i> (1993); von der Meden <i>et al.</i> (2017)	Inner Shelf 0-90 m	• Peak total % cover of marine invertebrates • Major decline in algae (incl. limit of deep kelp)
	Outer Shelf (saddle) 90 – 250 m	• Major declines in abundance of Bryozoa, Porifera, Polychaeta Bivalvia, Brachipoda, Ophiuroidea, <i>Nauticaris marionis</i> (crustacea) and Echinoidea • Increase in octocorallia from 250 m
	Shelf edge (incl. Shelf Edge) 250-500 m	• Secondary, minor increase in total abundance • Major increase in Octocorallia • Slight increase in Bivalvia • Stable, low abundance of other groups
	Upper Slope 500-1000 m	• Octocorallia continues to increase • Secondary declines in total abundance
Brandt <i>et al.</i> (2009); Douglass <i>et al.</i> (2014)	Mid Slope 1000-1800 m	• Decline and stabilisation in diversity of Isopoda, Polychaeta
	Lower Slope 1800-3500 m	• Distinct mollusc assemblage • Isopod species richness continues to increase
	Abyss > 3500m	• Isopod species richness peaks from 3000 m • Globally typical polychaete assemblage begins • Low gastropod and polychaete species richness

Shore types

The shores at the PEIs are critical for marine mammals (Pistorius *et al.* 2001, Chown and Froneman 2008), seabirds (Ryan, Cooper, *et al.* 2003), shorebirds like the endemic lesser sheathbill *Chionis minor* (Huyser *et al.* 2000), mites, insects (Mercer *et al.* 2000, Pugh and Mercer 2001) and intertidal ecosystems (Figure 19) (De Villiers 1976, Blankley and Grindley 1985).



Figure 19 The shores of the Prince Edward Islands are critical for many seabirds such as these Macaroni Penguins. Photo: Otto Whitehead.

Shores are defined as the area between the low-water spring tide mark and the upper limit of the salt-spray influenced supralittoral zone. This upper supralittoral limit in highly exposed areas can be as much as 300 m landward (Chown and Froneman 2008). Shore types were categorised based on existing descriptions of shore form (geomorphology), substratum type and wave exposure (related to aspect) at Marion Island (De Villiers 1976, Blankley and Grindley 1985). Additionally, high resolution satellite imagery (Worldview 2, Multi-spectral 4-band, 1.8m resolution, acquired January 2012) allowed the classification of shore types at Marion Island to be applied to Prince Edward Island (Figure 25).

Five shore types have been described previously at Marion Island based on geomorphology: 1) *vertical cliffs* of up to 30 m in height, 2) *sloping unbroken rock*, 3) *low relief rocky shelves* often noted at the base of cliffs, 4) *broken shores* formed by boulders present as strips fringing the base of cliffs or as boulder beaches, 5) *coarse volcanic sand beaches* which are rare and dynamic (De Villiers 1976). The young volcanic nature of the PEIs, ~0.45 mya (Quilty 2007), means that shores are structurally complex but their form and substrata are not hugely varied. The present classification therefore simplified these descriptions to three shore types based on geomorphology: 1) cliff with fringing broken rocky shore, 2) broken rocky shores (without cliffs) and 3) mixed shores with boulders and sand (Table 6).

Table 6. Elements of the classification for island shores and the resulting shore types.

Shore Form	Substratum Type	Exposure	Shore Type
Cliff and Broken Shore	Rocky	Highly Exposed	Highly Exposed Cliff and Broken Shore
		Exposed	Exposed Cliff and Broken Shore
		Least Exposed	Least Exposed Cliff and Broken Shore
Mixed	Boulder and/or volcanic sand	Least Exposed	Least Exposed Mixed Shore

Wave action is a major determinant of the physical characteristics of intertidal shores and beach morphology, and can strongly influence the structure of intertidal assemblages (Dayton 1971, McQuaid and Branch 1984, McLachlan *et al.* 1993). For Marion Island, De Villiers (1976) describes the littoral as ubiquitously exposed, with no headlands or bays to afford truly sheltered shores. The prevailing westerly winds and swell results in clear differences in exposure between western and eastern shores. Western shores experience intense gale force winds for more than 100 days a year and are highly exposed to ocean swell that move over deep water until very close to shore (De Villiers 1976, Chown and Froneman 2008). Due to the refraction of prevailing swell, the south-western and north-western shores are considered highly exposed. The eastern shores experience dissipated wave action but remain exposed, while a small section of the northeast coast is the least exposed (De Villiers 1976).

Based on the three geomorphological shore forms and the information on wave exposure, four shore types were recognised: Highly Exposed Cliff and Broken Shore; Exposed Cliff and Broken Shore; Least Exposed Cliff and Broken Shore; and Least Exposed Mixed Shore (Table 6). To map these shore types, a 15 m buffer was created around each of the island shoreline polygons. The buffer was sub-divided according to the four shore types using landmarks from historical descriptions of Marion Island and satellite imagery of both islands. If nearshore rocks were present within or in close proximity to the shore buffer, they were merged with the nearest shore type.

Neritic: Shelf and Shelf Edge

To identify relevant bathomes, local benthic fauna data were consulted where available. For shelf ecosystems, data from historical and contemporary surveys done at the PEIs identified three bathomes: Inner Shelf (0 – 90 m), Outer Shelf (90 – 250 m) and Shelf Edge (250 – 500 m; Figure 20). These were based on

abundance patterns (Table 5) of algae and ten benthic invertebrate groups (phyla), comprising Bryozoa, Brachiopoda, Porifera, Bivalvia, Polychaeta, Ophiuroidea, Echinoidea, Octocorallia and a decapod crustacean (Branch *et al.* 1993, Von der Meden *et al.* 2017).

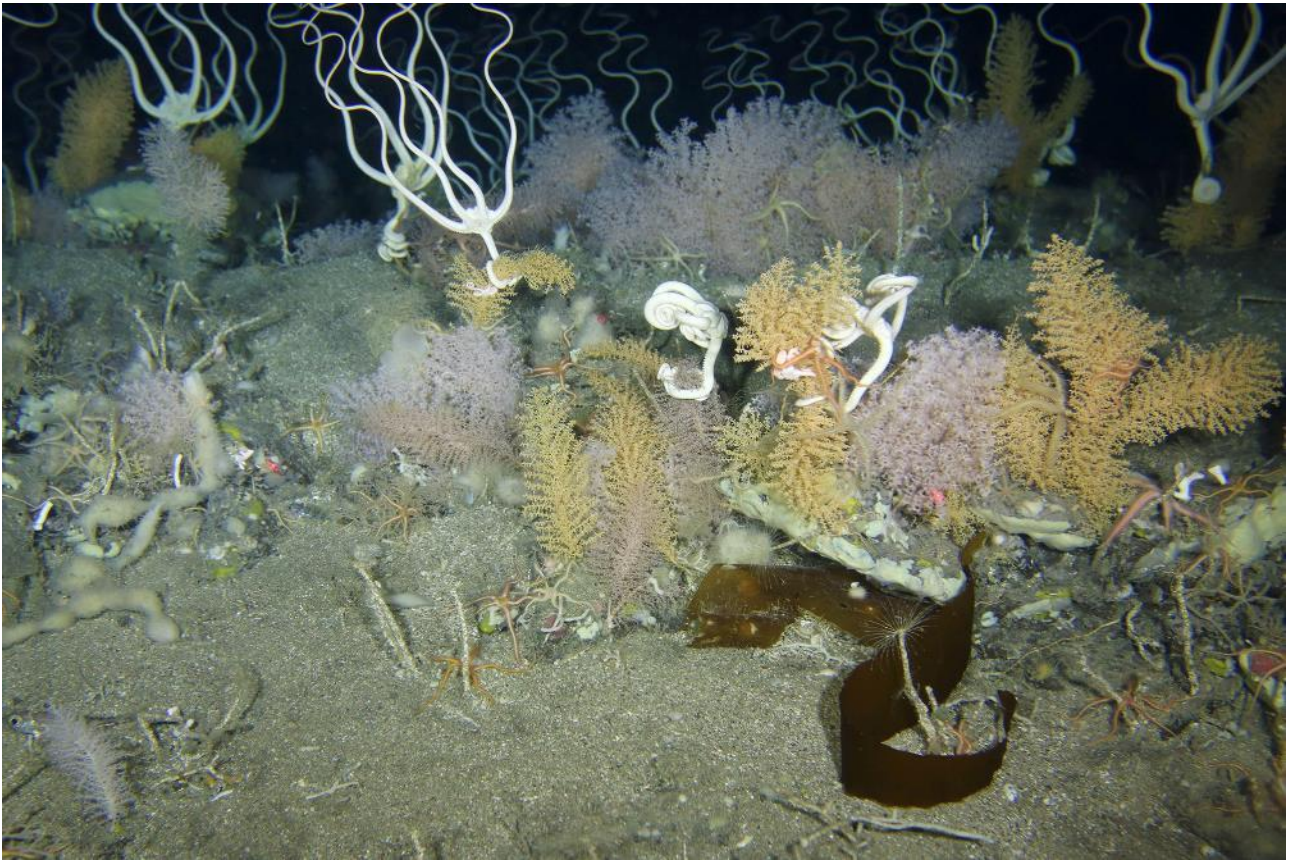


Figure 20 Brittle stars cling to soft corals on the Shelf Edge at 300 m. Photo: Grant van der Heever/SAEON.

Oceanic: Upper Slope to Abyss

In the absence of sufficient local biological data for the slope and abyssal areas in the sub-Antarctic territory, regional studies of the Southern Ocean, the Antarctic continental shelf and peninsula and similar sub-Antarctic oceanic islands were used to create a regionally explicit consensus of depth related faunal patterns (Table 7). This consensus was largely driven by an extensive characterisation of diversity patterns in Southern Ocean Bivalvia, Gastropoda, Isopoda and Polychaeta (Brandt *et al.* 2009), and the related bathome descriptions of Douglass *et al.* (2014). In this way, deep sea areas were classified into Mid Slope (1000-1800 m), Lower Slope (1800-3000 m) and Abyssal (>3000 m) bathomes, but with the narrow intermediate (1500-2000 m) bathome being discarded as too fine a resolution for this classification. The sub-Antarctic territory did not have any ecosystems at Hadal depths (>4500 m) so this bathome was not included in the classification.

Table 7. Key literature reviewed to establish ecologically defined depth patterns based on regional work, studies of the Antarctic shelf, and Southern Ocean islands. Cited literature for biological patterns as per Douglass et al. (2014). Abbreviations: Poly = polychaeta, Biv = Bivalvia, Gas = Gastropoda, Iso = Isopoda.

Regional, Southern Ocean		Antarctic peninsula and surrounds				Oceanic islands	
Douglass et al. (2014) Multi-species	Brandt et al. (2009) (Biv, Gas, Iso, Poly)	Gorny (1999) Decapoda	Vanhove et al. (1999) Nematoda	Neal et al. (2017) Polychaeta	Aldea et al (2008) Biv, Gas	Arntz et al. (2006) Multi-species	Kaiser et al. (2008) Multi-species
0-100 m Seaweed & herbivore limit ¹ Poly richness highest ⁴ Limit for some pycnogonids ²	0-250 m All taxa peak	0-130 m Shallow anomurans and brachyurans	Shelf < 500m Distinct fauna	Shelf <500m Distinct fauna	Shelf 0-400m Gradual rate of succession in both groups	Shallow shelf 200-300m	Shelf 300 & 500m
100-200 m Limit of wave and light, chlorophyll ³ Decline in Poly richness		130-500 m Shallow caridea Start of Palinura & Astacidea				Outer shelf 440m	
200-500 m High gastropod species richness ⁴ <i>Zanchlorhynchus spinifer</i> range starts ⁵		250-500 m All decline, with distinct shift in Biv & Iso					
500-1000 m Upper slope Mollusc assemblage ⁶ Echinoids <1000m (Chone et 03) ⁷ Lower fish den (williams 95) ⁸ Bryozoans restricted < 1000m ⁹	500-1000/1200 m All decline but Iso, Biv & Gas = local peaks at 1000m (halve in richness beyond this point)	450/500-750 m Antarctic & antiboreal species end; Peak in Palinura & Astacidea	Shelf break 500 m Distinct fauna; Upper slope 500-1000 m Distinct fauna		Upper slope 400 m 800 m	Upper slope 800-1500m	Slope 1000-1500m
1000-1500 m Slow decline and stabilisation in Biv, Gas and Poly diversity, ⁴	1000-1800/2000 m Slow decline and stabilisation in diversity Iso, Poly	750- 1500 m Peak in deep caridea		Distinct Deep shelf troughs 1000-1500 m	Lower slope 800-2000 m (to 3300 m for bivalves)		
1500-2000 m ANDEEP shelf isopods outer limit ¹⁰ Lower slope mollusc assemblage ⁶			Downslope 1500-2000 m Distinct fauna	Open slope +1500 m Distinct fauna			
2000-3000 m Isopod species richness continues to increase ⁴ Main deep extent Pectinariidae (Poly)		2000-2500 m Deep anomuram zone & end of deep caridea					
3000-4500 m Iso species richness peaks ⁴ Gas, Poly species declines ⁴ Unique Echinoids <i>E. amphora</i> and <i>P. debilis</i> ⁷ Typical deep sea Poly assemblage. ¹¹	3000-4500 m All decline. Sharply in the case of Iso. Local shift in Biv at 3500m						

+4500 m Iso, Poly richness declines ⁴	+4500 m Rapid decline Iso & Poly						
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Geomorphology and substrate type

The next level in the classification aimed to subclassify ecosystems within bathomes using geomorphological features of the seafloor. Such features are proxies for ecologically influential habitat characteristics including substrate type (hard vs soft), and current regimes that controls sediment deposition and erosion (O'Brien *et al.* 2009). Geomorphology and substrate type have been widely used in Southern Ocean classifications and bioregionalisations of seafloor habitats (Beaman and Harris 2005, O'Brien *et al.* 2009, Harris and Baker 2012, Koubbi *et al.* 2012, Douglass *et al.* 2014). Benthic communities are strongly influenced by substrate type because of differences in the availability of hard substrates for attachment and of soft sediment for anchoring or burrowing by benthic invertebrates (e.g. Kostylev *et al.* 2001, Sahade *et al.* 2004). Five major features are influential in the sub-Antarctic territory: 1) the Southwest Indian Ridge (SWIR), 2) a northerly area of plateau and seamounts, 3) the central plateau on which the islands sit, 4) deep abyssal plains to the south and southwest of the islands, and 5) the central eastern sector which falls on part of the Africana II Rise. In this eastern sector and to the extreme south-eastern limit of the EEZ, the habitats are linked to the Del Caño Rise and the Ob and Lena Seamounts respectively (Lombard *et al.* 2007, Douglass *et al.* 2014).

Using a recently created map of Antarctic seafloor geomorphology for the Southern Ocean (O'Brien *et al.* 2009), bathomes were subclassified according to key geomorphological features and their inherent substrate properties. Patterns of biodiversity unique to benthic habitats with particular slope or substrate characteristics were distinguished, even if within a single bathome. This is important for instance where the Inner Shelf bathome of the island plateau is differentiated from ecosystems within the same depth range on a shallow offshore seamount. Six of 28 Southern Ocean geomorphic features described by O'Brien, Post and Romeyn (2009) and mapped by Douglass *et al.* (2014) are represented within the sub-Antarctic territory: seamounts, seamount ridges, plateau, plateau slope, abyssal plain and troughs. In the delineation and description of these features, the authors aimed to improve prediction of the physical conditions that influence benthic biodiversity. It was therefore possible to use the descriptions in O'Brien, Post and Romeyn (2009) and Douglass *et al.* (2014), to broadly define the probable substratum types linked to each feature as hard, mixed or soft (Table 8).

Table 8. Substrate types of offshore geomorphic features found within the sub-Antarctic territory. Descriptions of features are from ¹Douglass *et al.* (2014); substrate type classifications for these features are based on ²O'Brien, Post and Romeyn (2009).

Feature	Description ¹	Feature classification ²	PEI classification
Seamount	Roughly circular areas which rise above the surrounding sea floor by at least 1000 m. [IHO differentiates seamounts (>1000m), knolls (500-1000m), hills (100-500m)].	Hard	Hard
Seamount/Spreading ridges	Elongate ridges that protrude hundreds to thousands of meters above the surrounding sea floor. Their shape has the potential to influence deep current activity.	Hard	Hard
Plateau	Relatively flat regions elevated above the surrounding sea floor by more than a few hundred meters (implied possibility of hard and soft substratum).	Not explicitly defined	Mixed
Plateau slope	Broad regions sloping from the margins of large plateaus to the surrounding deep ocean floor. (implied possibility of canyons and sediment gravity flows).	Not explicitly defined	Mixed
Abyssal plain	Extensive, flat, gently sloping or nearly level region of sediment covered seafloor at abyssal depths.	Soft	Soft
Rift valley and Trough	Closed elongate depressions (in the ocean floor) more than 4500 m deep and hundreds of kilometres long, generally associated with fracture zones.	Soft	Soft

Mapping the seafloor geomorphology and substrate types relied on two published spatial layers: global seafloor geomorphological features (Harris *et al.* 2014) and regional Antarctic seafloor geomorphology (O'Brien *et al.* 2009, Douglass *et al.* 2014). The regional Antarctic layer was the most relevant for the sub-Antarctic territory and the global layer served as a check. Features indicated in the global layer that did not appear in the Antarctic layer were assessed in relation to bathymetry and included where there was alignment. Features that were present in both layers but demarcated by different boundaries, were merged using the extent of the broadest feature. For example, Troughs (Antarctic layer) and Rift Valleys (global layer) both identify deep 'valley' features of the SWIR, but as Troughs were the broader feature, they were used to delineate the merged feature named Rift Valleys and Troughs. In some cases, boundaries of emergent features were adjusted to follow bathymetry. Some mapping rules and approaches were specific to particular feature types and are described below:

- Seamounts were the dominant layer and were prioritized from the Antarctic layer. Those from the global layer that intersected with the Antarctic later were deleted. A source field was added to mark seamounts that were unique to the global layer. Where these seamounts made sense in relation to bathymetry they were merged with the Antarctic layer to form a complete list of seamounts in the sub-Antarctic territory. Shallow seamounts were defined as those reaching the 90-250 m depth zone and classified the entire feature (following Douglass *et al.* 2014).
- The Spreading Ridge feature of the SWIR was mapped by merging 'seamount ridge' and 'spreading ridge' geomorphological features. This new feature was based on the 'spreading ridge' layer but included areas where seamount ridges extended beyond its boundary. During mapping, a small area within the Spreading Ridge was classified as 'upper slope' but was merged into Spreading Ridge to avoid creating a single unique ecosystem class.
- Within the SWIR, Troughs (Antarctic layer) and Rift Valleys (global layer) were merged to form a single feature type called Rift Valleys and Troughs. Since the Rift Valleys were contained within Trough features, the extent of the merged feature was mapped using the boundaries of the larger original Trough feature. The majority of this feature type occurred at abyssal depths but was called 'Deep Rift Valleys and Troughs'. These boundaries were manually delineated to distinguish Deep Rift Valley and Trough features of the SWIR from adjacent abyssal ecosystem types (Temperate and Sub-Antarctic Abyss). Boundaries were created across the 'mouth' of each Rift Valley and Trough by projecting the border of the spreading ridge across the 'mouth' of the valley features, or by closing the feature at the narrowest point of the 'mouth'.
- Plateau features trumped the Spreading Ridge (as with Seamounts) and so the Plateau boundary was used where these two features overlapped. Plateau features were further separated into Plateau and Shallow Plateau types, with depths of 90 – 500 m considered as Shallow Plateau. The 90 – 250 m zone applied to Seamounts was not used because the 'shelf edge' depth zone of plateaus had no name equivalent to the island-associated definition of 'shelf edge'. Additionally, the deeper areas of Plateau features were mapped according to bathymetric depth breaks to represent plateau slope ecosystem types, such as Mid Plateau or Lower Plateau.
- Abyssal Plains were mapped as depths > -3500 m. However, several areas identified as abyssal plain features in the Antarctic seafloor geomorphology layer were shallower than 3500 m, and were classified as Lower Slope. In the Temperate ecoregion, there was an instance where the -3500 m isobath did not intersect with the edge of the EEZ, which was manually corrected by extending a straight line in the original northeasterly direction of the isobath to edge of the EEZ.

Additional descriptive layers

Three entirely new biological datasets were compiled and mapped that do not yet form part of the classification itself but contribute to descriptions of ecosystem types and inform elements of the ecosystem assessment. These layers delineate kelp populations, areas of importance for foraging top predators and occurrence records of benthic Vulnerable Marine Ecosystem (VME) indicator taxa. It is likely that these will be used to refine the marine ecosystem classification in future assessments of the sub-Antarctic territory.



Figure 21. Bull kelp (*Durvillaea antarctica*) occurs along the cliff shorelines of Marion and Prince Edward Islands and is subject to constant wave action. Photo: Otto Whitehead.

Kelp

Kelps, particularly the giant kelp *Macrocystis pyrifera*, are highly influential components of coastal ecosystems, ranking as one of the most ecologically productive systems in the world (Foster and Schiel 1985, Graham *et al.* 2007). They are primary producers, providing biogenic habitat through the water column and positive facilitation that supports many higher organisms (Ojeda and Santelices 1984, Kaehler *et al.* 2000, 2006, Pakhomov *et al.* 2002, Lescroël *et al.* 2004, Arkema *et al.* 2009). Kelp beds have been included as 'biological facies' or 'biotopes' in ecosystem classification schemes in Australia and the USA (e.g. (Last *et al.* 2010, Pittman *et al.* 2011). Although kelp habitats have not featured prominently in broad (circumpolar scale) ecosystem classifications of the Southern Ocean, they are certainly recognised as key habitat types or biotopes at the island-scale for Kerguelen, Crozet and Prince Edward Islands, and are one of the biodiversity features identified for future use in systematic conservation planning within this CCAMLR domain (Koubbi *et al.* 2012, Koubbi *et al.* 2016a). In addition to their established ecological importance, parts of the *M. pyrifera* population at the PEIs are the deepest known anywhere in the world (68-73 m; (Dickie 1877, Perissinotto and McQuaid 1992). This is roughly twice as deep as existing records for populations elsewhere in the Southern Ocean, such as at Kerguelen (40 m) and Crozet islands (25 m) (Perissinotto and McQuaid 1992). A further imperative to include descriptions of kelp distribution at the PEIs comes from evidence of their vulnerability to changing oceanography, with large-scale declines and shifts of *Macrocystis* and associated assemblages seen in eastern Tasmania (Edgar *et al.* 2005, Ling 2008, Johnson *et al.* 2011). The ecological changes off

Tasmania are considered some of the most significant marine ecosystem shifts reported (Filbee-Dexter and Scheibling 2014).

Surface evidence of kelp was mapped at the PEI using satellite imagery and adapted methods of (Cavanaugh *et al.* 2010). Two images from the Sentinel 2 satellite taken in May 2017 were selected, giving full coverage of both islands. Summer samples were preferred because biomass and production are increased and show the maximum kelp extent (van Tussenbroek 1989). Atmospheric correction was done using the Sen2Corr script (ESA). Following the correction, bands B2 (blue) and B8 (Near Infra-Red) at 10m resolution were analysed with a normalised difference algorithm to identify kelp pixels. This was preferred over the Normalized Difference Vegetation Index (NDVI), used in terrestrial vegetation mapping, as it more reliably separated cloud brightness from kelp signal. Island land masses were removed using a land mask and a threshold (> 0.2) applied to select all kelp pixels and output a shapefile denoting presence or absence. This method primarily identified *Macrocystis pyrifera* at or near (< 1 m) the sea surface (Cavanaugh *et al.* 2010). Deeper kelp beds at Natal Bank were mapped using the 75 m isobath as the lower limit, which covers their known depth distribution on the feature (Figure 25a; (Perissinotto and McQuaid 1992). Their contemporary presence was confirmed during tow-camera sampling in 2015 when extensive *M. pyrifera* beds were observed at ~60 m (Figure 25a).

Important foraging areas for top predators

Marine top predators are functionally important in marine ecosystems as top-down structuring agents of lower level communities (e.g. (Baum and Worm 2009). The distributions of foraging top predators are useful descriptors for mapping marine ecosystems as they themselves track the distribution and abundance of prey species, and thereby identify ecologically important areas (Boyd and Murray 2001, Moore 2008, Durant *et al.* 2009). While this relationship identifies changeable, dynamic processes such as productive ocean fronts, the use of long-term tracking data from multiple species, together with the latest modelling approaches, highlights areas of intense use that represent important pelagic habitats (Reisinger *et al.* 2018). The relationship between top predators and the pelagic environment in the sub-Antarctic territory is particularly important, as foraging predators identify important areas around major fronts and mesoscale eddies (Nel *et al.* 2001, Bost *et al.* 2009, de Bruyn *et al.* 2009, Whitehead *et al.* 2016). Many predators also use bathymetric features, such as the Sub-Antarctic Fur Seals that feed at the Del Cano Rise during lactation (de Bruyn *et al.* 2009). Recent evidence also identifies the Galieni Bank feature to the east of Marion as an important foraging area for King Penguins (Pistorius *et al.* 2017a). These descriptions of ecologically important foraging areas are likely to enhance future ecosystem classifications. Using the habitat suitability models of Reisinger *et al.* (2018), habitat importance scores were calculated based on percentile-transformed habitat preference predictions for 14 species of top predators within the sub-Antarctic territory (see Appendix B). Multi-species composite scores were then calculated and mapped by summing the integer habitat importance scores for all 14 species. This information was used to provide descriptions of top predator habitat importance for the mapped ecosystem types (see extended ecosystem type descriptions, Appendix D).

Vulnerable Marine Ecosystem indicator taxa

The paucity of biological information from much of the global seafloor, particularly the Southern Ocean, makes it difficult to assess benthic biodiversity. At the PEIs, benthic biodiversity data is available for depths less than 600 m (Branch *et al.* 1993, Von der Meden *et al.* 2017) but little is known about deeper habitats. For such areas, proxies must be used to describe benthic ecosystems (Reiss *et al.* 2015). In the Southern Ocean, Vulnerable Marine Ecosystems (VME) have broad ecological significance and can provide information for areas where occurrence data is routinely collected by fisheries (CCAMLR 2009a, Jones and Lockhart 2011, Koubbi *et al.* 2016b).

Vulnerable Marine Ecosystems (VME) indicator taxa are functionally important benthic organisms that are vulnerable to physical disturbance and are identified by CCAMLR using seven criteria (CCAMLR 2009b, 2009a, Jones and Lockhart 2011). VME indicator taxa are useful indicators of benthic biodiversity (e.g. (Wood *et al.* 2012, Beazley *et al.* 2013) and are linked to surrounding environmental conditions, including geomorphology, sedimentation and hydrographic regimes (Beaman and Harris 2005, Post *et al.* 2010), making them useful to descriptions of benthic ecosystems. Mapping VMEs therefore provides broad information about functional ecology and biodiversity even when using relatively sparse point occurrence data (Figure 22).

For the present assessment, three data sources were combined to form the occurrence dataset for habitat-forming VME taxa: CCAMLR VME data extracted from the fisheries observer program, Iziko South African Museum records for the EEZ, and the SOMBASE-BIOCONSTRUCTORS dataset extracted from the Global Biodiversity Information Facility (Survey 2017). The VME dataset included occurrences of 27 CCAMLR VME taxa (see Appendix C) obtained with permission from the former Department of Agriculture Forestry and Fisheries and CCAMLR for the period 2009 (when VME record keeping in this sector began) to 2017. The SOMBASE-BIOCONSTRUCTORS dataset similarly identifies benthic invertebrates considered to have rigid, complex growth forms that provide habitat and enhance biodiversity. The groups include sponges, corals, bryozoans and hydroids. The intention behind this combined dataset was to balance the fishery related CCAMLR VME data, which is spatially limited to areas targeted by long-line demersal fishing activities, with research data from the SOMBASE dataset (derived from a variety of sources) to improve the coverage of data throughout the EEZ.

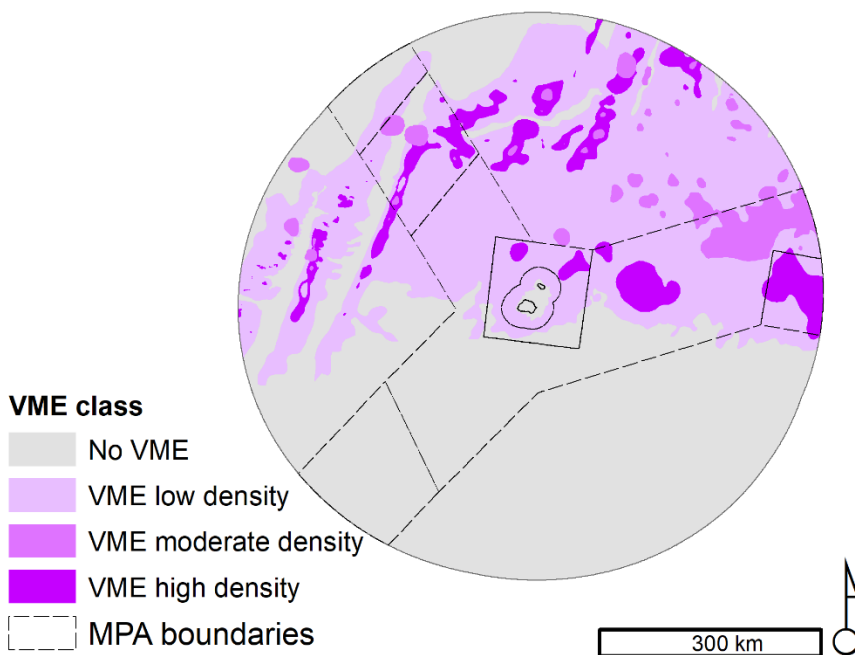


Figure 22: Areas of high, moderate and low density of VMEs were mapped in the sub-Antarctic territory.

Marine ecosystem map and overview

The sub-Antarctic territory marine ecosystem map captures 11 broad ecosystem groups by integrating spatial layers of key environmental data with biological information and patterns. Through these intersections, the map identifies four benthic-pelagic ecoregions (Figure 18) and 29 distinct marine ecosystem types (Figure 23) that nest within regions defined by bathymetry. The ecosystems are described below, grouped by their respective ecoregions, starting from the largest and most complex region to the least complex. An overview of all ecosystem types is given in Table 9.

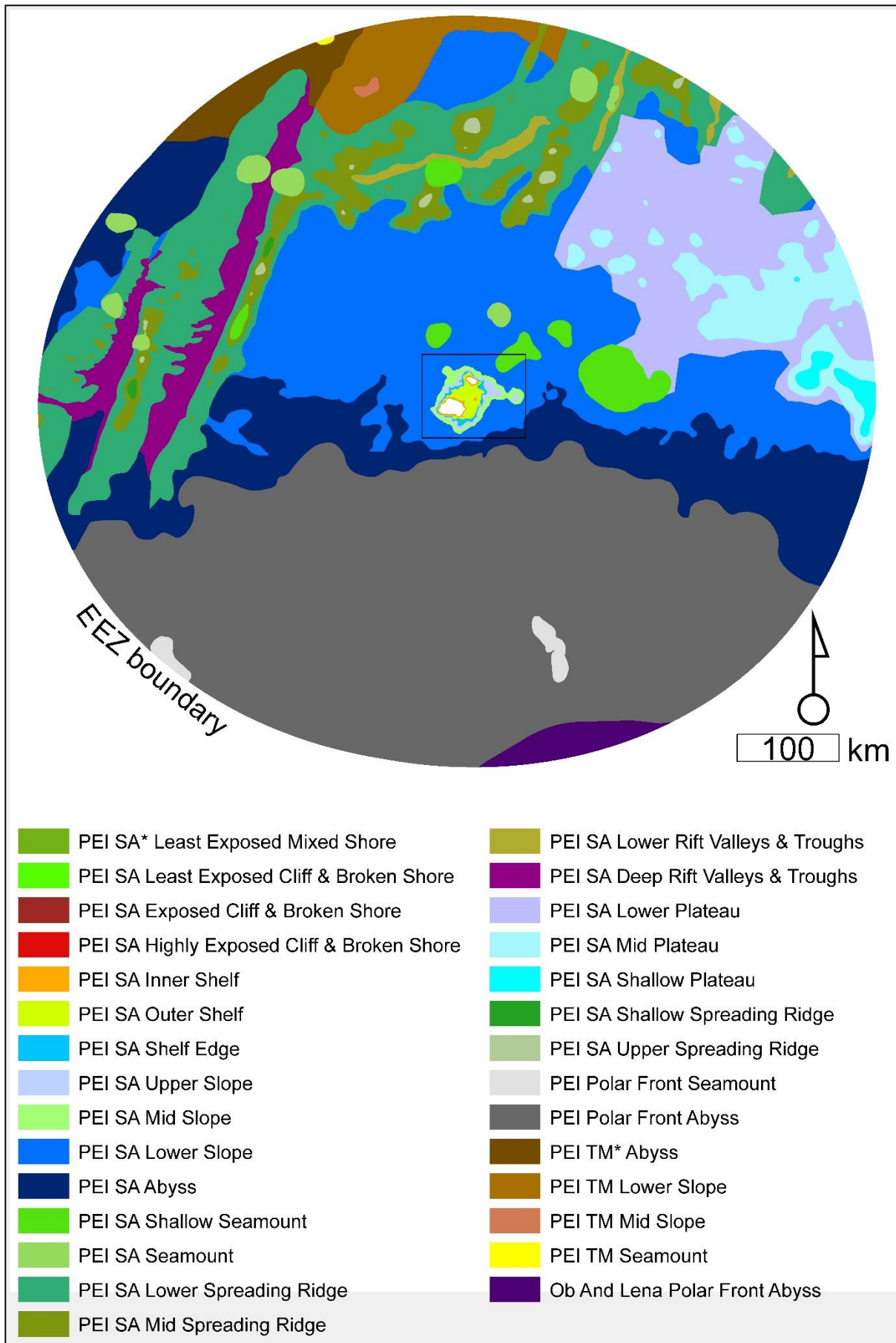


Figure 23. The Marine Ecosystem Classification for the sub-Antarctic territory identified 29 ecosystem types across four benthopelagic ecoregions.

PEI Sub-Antarctic Ecoregion

Of the four biogeographical units that characterize the sub-Antarctic territory, the Sub-Antarctic ecoregion was the largest by area and the most complex. Within this ecoregion, 22 ecosystem types were identified, encompassing all island shore types, island associated shelf and slope types, the entire extent of the SWIR that lies within the EEZ, 13 seamounts (including all six shallow seamounts), major plateau ecosystems to the east and intervening areas comprising lower slope and abyssal ecosystem types.

Shore types

Four shore ecosystem types were distinguished (Figure 25b, c, and Table 6) based on further sub-classification by wave exposure. The two least exposed ecosystem types describe the protected eastern shores of each island. These were the *PEI sub-Antarctic Least Exposed Mixed Shore* (Marion Island) and the *PEI sub-Antarctic Least Exposed Cliff and Broken Shore* (Prince Edward Island). While broad differences in shore geomorphology distinguish these shore types, they comprised the largest variety of forms and mixed substrate types. Intertidal communities are similar and are typical of sub-Antarctic islands (De Villiers 1976). Shores are dominated by algae, with the rhodophyte *Porphyra* being the most common in the upper to mid littoral, where it is interspersed with *Enteromorpha bulbosa*. A distinct 'break' in community structure is formed by the fucoid *Durvillea antarctica* that dominates the lower littoral. This transitions to a rhodophyte zone in the upper sub-littoral that includes *Schizoseris*, *Polysiphonia* and *Lithothamnium*. Intertidal invertebrate assemblages include bivalves (*Kidderia bicolor* and *Lasaea consanguinea*), several species of amphipod and tanaid, and two limpet species (*Nacella delesserti* and *Kerguelenella lateralis*). The giant kelp *Macrocystis pyrifera* is abundant in adjacent nearshore zones.



Figure 24 Ships's Cove (a) is a Least Exposed Mixed Shore on the east coast of Marion Island, vastly different to the Highly Exposed Cliff and Broken Shore ecosystem type (b) that dominates the west coasts of both islands. Photos: Otto Whitehead.

The *PEI sub-Antarctic Exposed Cliff and Broken Shore* ecosystem type identified the obliquely exposed south-eastern shores of both islands. These shores comprised cliffs with fringes of broken rock and some high relief rocky shores. Giant kelp remained common to abundant in the nearshore zone. The western coasts were defined by *PEI sub-Antarctic Highly Exposed Cliff and Broken Shore* ecosystem type. These were dominated by sheer cliffs with minimal fringes of high relief broken rocky shore providing a far narrower intertidal zone. The abundance of giant kelp declines in these westward areas, with only smaller isolated patches being

evident. All shore ecosystem types are used to some extent by various marine top predators. King Penguins (*Aptenodytes patagonicus*), Southern Elephant Seals (*Mirounga leonina*) and Antarctic Fur Seals (*Arctocephalus gazella*) use accessible parts of all shore types except the highly exposed western shore (Hofmeyr *et al.* 1997, 2012, Crawford *et al.* 2009). Rockhopper Penguins (*Eudyptes chrysocome*) are found across shore types, including highly exposed shores, while Macaroni Penguins (*Eudyptes chrysolophus*) primarily utilise the southern shores (Crawford *et al.* 2003a, 2003b). The western part of the *PEI sub-Antarctic Exposed Cliff and Broken Shore* also supports multiple high density rookeries of Subantarctic Fur Seals (*Arctocephalus tropicalis*) (Wege *et al.* 2016).

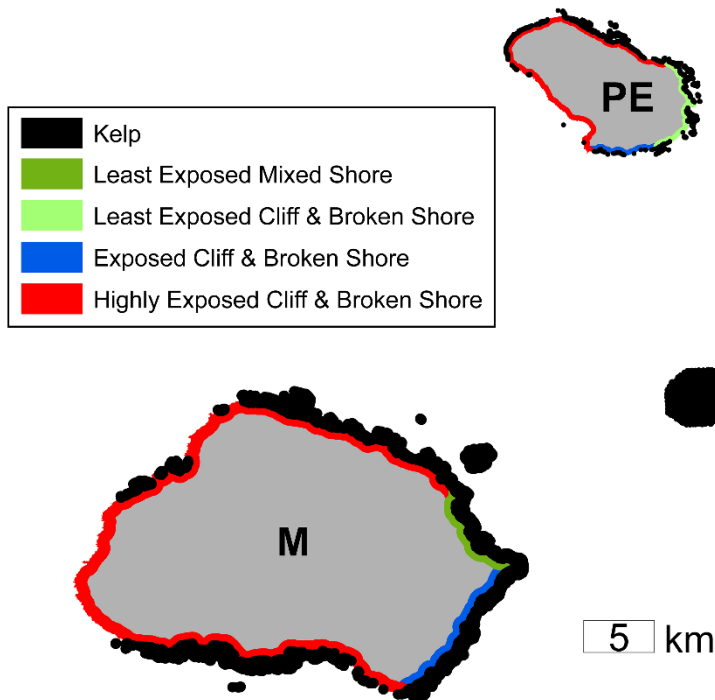


Figure 25. Stands of giant kelp *Macrocystis pyrifera* are shown in by black fringing around the islands (M = Marion Island; PE = Prince Edward Island), and by solid black area on Natal Bank that identifies the approximate extent of the only known deep kelp population. Due to difficulty in representing narrow kelp polygons at the island scale, the outer boundaries of the polygons have been emphasised in these figures.

Shelf and slope

The *PEI sub-Antarctic Inner Shelf* and *PEI sub-Antarctic Outer Shelf* ecosystems are island-associated and dominate the neritic zone (Table 9). These ecosystems support peak abundances of several benthic taxa including the bryozoa, porifera, polychaeta, brachiopoda, bivalvia, ophiuroida, echinoidea and the hyperbenthic shrimp *Nauticaris marionis*. Both ecosystems support several nototheniid fish species, particularly *Lepidonotothen larseni* and *Gobionotothen marionensis* in shallower inner shelf waters and *Lepidonotothen squamifrons* in outer shelf areas. The inner shelf is euphotic habitat characterised in its shallower parts by a subtidal zone of red algae and giant kelp. Benthic substrate types are soft tending to mixed on the western and south western sides of the island. The outer shelf is the island plateau with a saddle-like feature extending between the islands. The substratum is largely soft but with mixed substrate in parts, most significantly on the boulder-strewn feature called Natal Bank.

Beyond the outer shelf, the *PEI sub-Antarctic Shelf Edge ecosystem* is characterized by a steeper gradient, becoming rapidly deeper particularly off the western coast of Marion island and off the northern coast of

Prince Edward Island. As depth increases, most of the above-mentioned benthic invertebrate groups decline but the abundance of Octocorallia increases rapidly and to a lesser degree, the Bivalvia.

Defining the start of the oceanic zone, the *PEI Sub-Antarctic Upper Slope* and *PEI Sub-Antarctic Mid Slope* ecosystem types are loosely defined by depth contours following the island shelf edge in successive, relatively narrow, zones. Both however, have expanded 'lobes' to the east and northwest of the islands. Limited records of epibenthic biota suggest soft and mixed substrates are present in both ecosystem types. The upper slope is distinguished from the mid slope by a sustained increase in the Octocorallia, contrasting with depressed but stabilized diversity of other groups in the mid slope habitats.

Moving deeper the *PEI Sub-Antarctic Lower Slope* is the largest of the PEI Sub-Antarctic ecosystem types, and encompassed the central and eastern parts of the ecoregion. These areas are predominantly low relief seafloor of primarily soft substrate. Limited biotic data (VME records) confirm the presence basket stars and branching brittlestars, suggesting at least some mixed substrate types occur. The pelagic environment provides important foraging areas for a wide range of top predators, including the Endangered Indian Yellow-Nosed (*Thalassarche carteri*), Grey-Headed (*Thalassarche chrysostoma*) and Sooty Albatrosses (*Phoebastria fusca*). These areas are also important for Sub-Antarctic Fur Seals.

Abyss

The *PEI Sub-Antarctic Abyss* ecosystem forms another large portion of the Sub-Antarctic ecoregion. It is level or gently sloping and assumed to be mostly soft sediment habitat extending along the southern boundary of the ecoregion. Based on limited benthic records, the presence of Gorgonacea and Euryalida indicate that at least some mixed substrate exists. Like the adjacent lower slope ecosystem, it supports pelagic foraging by a wide range of top predators. These include Southern Elephant Seals and Vulnerable or Endangered albatrosses, particularly to the southwest and east.

Seamount and plateau

Major parts of the sub-Antarctic ecoregion are influenced by emergent features. Four centrally clustered shallow seamounts near the islands, and two dispersed on the SWIR, form the basis for the *PEI Sub-Antarctic Shallow Seamount* ecosystem type. These unique features rise from the lower slope bathome (1800 – 3500 m) to less than 250 m and are the shallowest 'non-island' emergent features within the sub-Antarctic territory. Similarly, the *PEI Sub-Antarctic Seamount* ecosystem type classifies seven deeper seamounts within the Sub-Antarctic ecoregion, which are mostly associated with the SWIR. Both seamount ecosystem types are considered as hard substrate features and support enhanced species diversity and abundance, as indicated by the high number of VME indicator taxa records from these features, including hard cold-water corals. Although seamounts include a wide range of bathomes, they are categorised as single ecosystem units because of their characteristic biophysical processes that enhance species diversity and abundance.

To the east of the islands lies an extensive plateau, which is comprised of *PEI Sub-Antarctic Lower Plateau*, *PEI Sub-Antarctic Mid Plateau* and *PEI Sub-Antarctic Shallow Plateau* ecosystem types. The *Lower Plateau* is the largest ecosystem type here, and comprises plateau slope habitat of soft and mixed substrate that rises from the deep ocean floor to 1800 m. Vulnerable Marine Ecosystems (VME) indicator records include Stylasterid corals, basketstars and branching seastars. The *Mid Plateau* ecosystem type is also composed of soft and mixed substrates, but includes sloping habitat and plateau areas within the mid slope bathome. At the eastern limit of the EEZ, the plateau slope rises above 500 m to form the *Shallow Plateau*, which is characterized by a flattened shallow area of mixed substrate known as Galieni Bank. The *Mid Plateau* and *Shallow Plateau* ecosystem types have rich benthic fauna, including black corals (Antipatharia), sponges,

bryozoans, and ophiuroids. The associated pelagic environments are also important for foraging top predators.

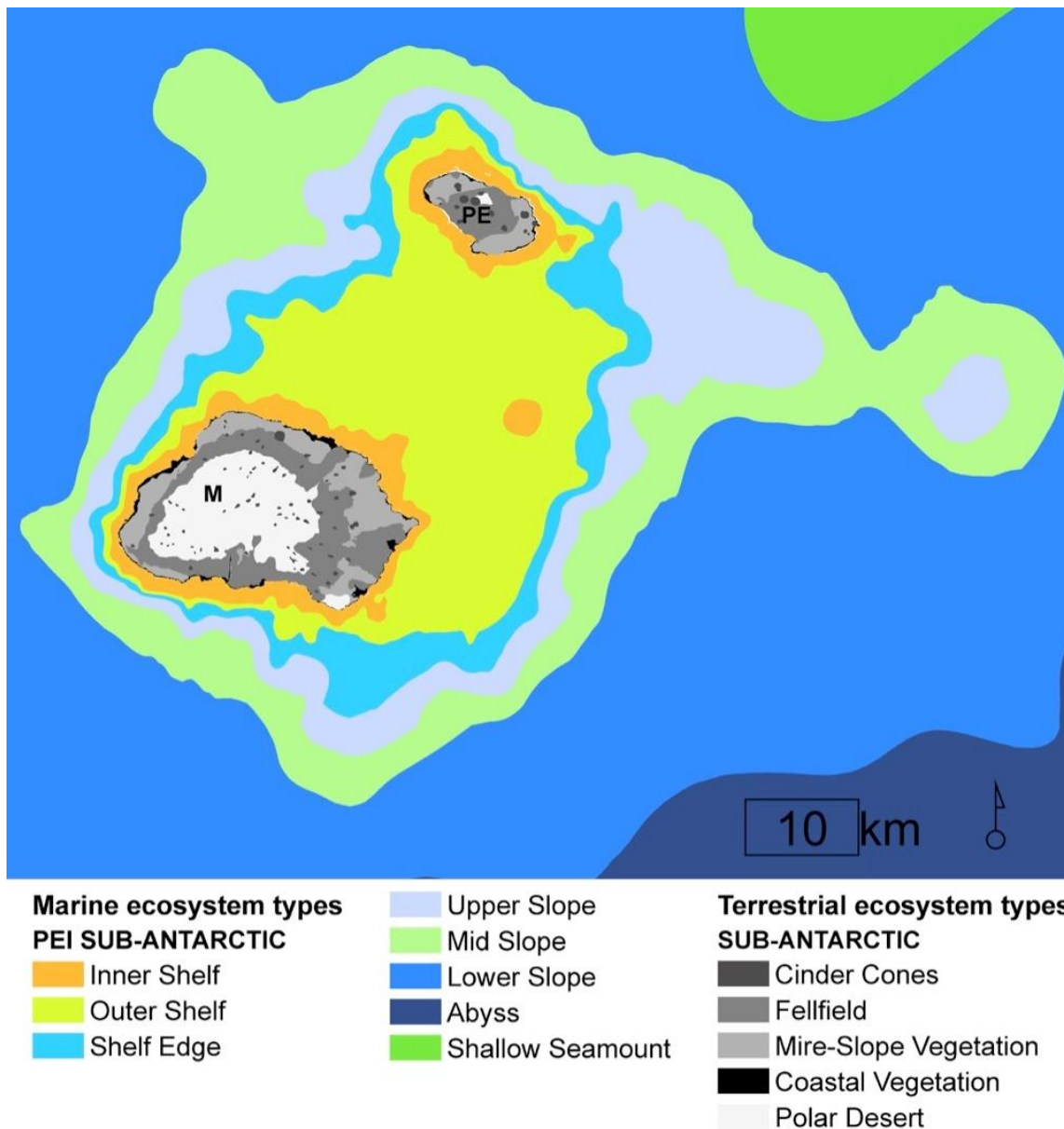


Figure 26. The five terrestrial ecosystem types of Marion (M) and Prince Edward (PE) with surrounding marine shelf and slope ecosystems.

Spreading ridge

The spreading ridge group refers to the part of the SWIR contained in the sub-Antarctic territory, which is the largest broad ecosystem group related to emergent geomorphological features in the PEI Sub-Antarctic ecoregion. The large extent and elevation of the elongated ridges means that they exert a strong influence on deep and upper water currents, influencing the pelagic environment over a vast area. The presence of hard substrate on the ridges provides structure for specific assemblages of benthic organisms. The spreading ridge group is classified into six ecosystem types: four that delineate elevated parts of the ridge and two that classify deep rifts and depressions between ridges.

The largest area of the four elevated parts of the ridge is formed by the *PEI Sub-Antarctic Lower Spreading Ridge* ecosystem type, which describes the deepest part of the SWIR slope and includes areas where slope begin to rise from the deep rift valleys and troughs that run between the ridges. The *PEI Sub-Antarctic Mid*

Spreading Ridge ecosystem type occupies the mid slope bathome that extends upwards from the lower slope. This includes hard ridge habitats that form the lower summit across substantial parts of the spreading ridge feature. This ecosystem type supports the highest number of VME indicator taxa records (347) of any ecosystem type within the sub-Antarctic territory. Above the mid slope, the *PEI sub-Antarctic Upper Spreading Ridge* ecosystem type describes 13 scattered peaks (tertiary summits) of hard substratum on the ridges of the SWIR, which at their shallowest reach depths of between 500 - 1000 m from the sea surface. Three small peaks in isolated parts of the SWIR reach depths of between 500 - 250 m from the sea surface (only the shallow seamounts reach shallower water) and are classified as *PEI sub-Antarctic Shallow Spreading Ridge*. These secondary summits are comprised of hard substratum.

The two ecosystem types that classify areas between the slopes and peaks of the spreading ridge are *PEI Sub-Antarctic Lower Rift Valleys and Troughs* and *PEI Sub-Antarctic Deep Rift Valleys and Troughs*. The former ecosystem type delineates troughs at depths of between 1800 – 3500 m, which are not true rift valley features, but rather long, narrow depressions found within the *PEI Sub-Antarctic Lower Spreading Ridge*. These troughs are likely characterised by soft substratum types. The two major rift valleys that bisect the western end of the SWIR within the sub-Antarctic territory were classified as *PEI sub-Antarctic Deep Rift Valleys and Troughs*. These extensive, elongated features represent the deepest ecosystem type found within the broader spreading ridge feature. No records of benthic biota have been recorded from these features but substratum is likely dominated by soft sediments. Although these rift valleys are unique within the sub-Antarctic territory, they are likely found in other parts of the SWIR. Top predators forage in pelagic environments in the western and central areas of the SWIR.

PEI Temperate Ecoregion

The PEI Temperate ecoregion is the northern-most biogeographic unit in the sub-Antarctic territory and encompasses four ecosystem types. This ecoregion is dominated by lower slope and abyssal ecosystem types, with the only raised geomorphological features being a single isolated mid slope ecosystem type and a small seamount on the northern boundary of the EEZ.

Slope and abyss

The *PEI Temperate Lower Slope* characterises the eastern half of the ecoregion while the *PEI Temperate Abyss* dominates western half. These are the largest and second largest ecosystem types in the Temperate ecoregion. Both ecosystem types are characterised by soft sediment plains and a gently sloping sea floor. Rising from lower slope habitats is a small slightly elevated area of soft seafloor classified as the *PEI Temperate Mid Slope* ecosystem type, which covers mid slope depths of between 1000 -1800 m.

Seamount

The *PEI Temperate Seamount* ecosystem type identifies a small seamount composed of hard substrate that rises from the surrounding deep abyssal habitat to within the upper slope depth range of 250 -500 m. While there are no records of VME indicator taxa from this ecoregion, it is an important foraging area for top predators including White-Chinned Petrels (*Procellaria aequinoctialis*), Orcas, and Sooty, Wandering and Indian Yellow-Nosed Albatrosses.

PEI Polar Front Ecoregion

The *PEI Polar Front Ecoregion* is almost entirely composed of deep abyssal plains and is strongly influenced by the Polar Front and colder waters to the south of the islands.

Abyss

The *PEI Polar Front Abyss* is the dominant ecosystem type within the Polar Front ecoregion and forms the largest continuous area of abyssal habitat in the sub-Antarctic territory. It is characterised by flat or slightly undulating plains of soft sediment, all deeper than 3500 m. There are no records of VME indicator taxa from this area but the productive pelagic environment of the Polar Frontal Zone is used by transiting and foraging top predators.

Seamounts

There are two isolated seamounts in the ecoregion that were classified as *PEI Polar Front Seamount*. The hard substrate and emergent nature of these features differentiates them from the surrounding abyss. Although there are no records of VME indicator taxa from these features, the associated pelagic environment serve as important foraging areas for top predators (Table 9).

Ob and Lena Polar Front Ecoregion

The *Ob and Lena Polar Front* ecoregion is the southernmost biogeographic unit in the sub-Antarctic territory. It is the smallest and least complex ecoregion, having a single ecosystem type, the *Ob and Lena Polar Front Abyss*. It is composed of soft, flat or gentle undulating plains typical of abyssal habitats but is distinguished from the surrounding abyss as it is influenced by the regionally defined Ob and Lena seamount ecoregion to the east of the sub-Antarctic territory (Douglass *et al.* 2014). No VME indicator taxa records exist for the region.

Constraints and recommendations

The sub-Antarctic territory is a large and remote territory for which long-term oceanographic and biophysical data (plankton, productivity, etc.) has been reasonably well captured over appropriate spatial and temporal scales. Equally, the region benefits from temporally continuous and advanced research on large marine mammals and seabirds (top predators). However, the insufficient biological data from deep-sea environments limited the assessment of marine biodiversity for the region, particularly because these represent the largest non-pelagic habitat in the sub-Antarctic territory. Similarly, direct knowledge of basic surficial sedimentology and geology is very limited. Although regional and global spatial layers based on model outputs are well developed, the limited direct knowledge of deep-sea environments provides an opportunity to advance research and understanding in the sub-Antarctic territory. This would increase confidence in future ecosystem classifications and assessments. Any data collection from the deep-sea is difficult and expensive but with the right partnerships, it is recommended that even low resolution sampling to test substantive cases (e.g. sampling a seamount slope to verify the substratum and benthic fauna) will be a significant advance in current knowledge. A benefit of any such work will be increased opportunities to monitor the territory for the appearance of non-native species and invasion.

Confidence

There is a high degree of confidence in the classification approach and its ability to capture key ecosystem attributes. The implementation of any classification is, however, dependent on the spatiotemporal coverage

and quality of data used. For the sub-Antarctic territory, biogeographic units were based on comprehensive regional data (existing ecoregionalisations; Douglass *et al.* 2014) that were refined using local oceanographic data. Similarly, bathomes were established using the most recent bathymetric and species distribution data that were refined using local data where possible. For shelf ecosystems, there was good agreement between regionally described depth transitions (bathomes) and the locally defined depth breaks based on local direct data. This suggests that regional depth patterns can be relied on to define deep-sea bathomes within the sub-Antarctic territory. While little direct geological or geomorphological data exist for the territory, the seafloor geomorphology layers used for the classification are the most recent, considering both the global and regionally refined layers.

Table 9. Summary of ecosystem types with descriptions for the marine ecosystem classification of South Africa's sub-Antarctic territory.

PEI TEMPERATE ECOREGION			
	Seamount 250-3500 m	84 km ²	A seamount comprising of hard substrate.
	Mid Slope 1000-1800 m	270 km ²	An isolated feature of soft substrate rising from surrounding lower slope habitat.
	Lower Slope 1800-3500 m	10,371 km ²	Soft sediment plain and gentle sloping seafloor. Largest ecosystem type in the ecoregion, covering the entire northern and eastern sectors.
	Abyss > 3500 m	5,843 km ²	Soft sediment abyssal plain that covers the western half of the ecoregion.
PEI SUB-ANTARCTIC ECOREGION			
	Least Exposed Mixed Shore	0.15 km ²	Sheltered eastern shores of Marion Island comprising mixed substrate types across high and low profile rocky shores with sections of boulders. Includes the only major sandy beaches.
	Least Exposed Cliff and Broken Shore	0.16 km ²	Sheltered eastern shores of Prince Edward Island comprising steep cliffs with fringes of broken rock interspersed with high relief rocky shores.
	Exposed Cliff and Broken Shore	0.33 km ²	Obliquely exposed south-eastern shores of both islands, comprising cliffs with fringes of broken rock and some high relief rocky shores.
	Highly Exposed Cliff and Broken Shore	1.68 km ²	Directly exposed western and north-western shores of both islands, characterised by highly exposed sheer cliffs with lesser fringes of broken rock.
	Inner Shelf 0-90m	163 km ²	Island-associated plateau within euphotic zone. Includes shallow subtidal zone of red algae and benthic habitat characterised by flat or low relief soft substrate that is more mixed on the western and north-western sides of the islands.
	Outer Shelf 90-250 m	706 km ²	Island-associated plateau within the neritic zone. Mostly soft substrata with discrete areas of mixed ground. Includes shallow saddle-like feature between islands and a small rocky pinnacle called Natal Bank.
	Shelf Edge 250-500 m	301 km ²	Seafloor habitat on shelf edge side of island plateau at the limit of the neritic zone. Soft and mixed substrate with increased gradient, particularly to the west of Marion Island and north of Prince Edward Island.
	Upper Slope 500-1000 m	603 km ²	Narrow bathome following contours of the island shelf edge but expands to the east of the islands. Limited data suggests soft and mixed substrate.
	Mid Slope 1000-1800 m	1,021 km ²	Narrow bathome following contours of the island shelf but expands to the east and northwest of the islands. Presence of soft and hard substratum dwelling taxa suggest soft and mixed substrate.
	Lower Slope 1800-3500 m	85,504 km ²	Level or low relief seafloor dominating the central and eastern parts of the ecoregion. Limited data suggests soft and mixed substrate including discrete rocky patches. Largest ecosystem type in the Sub-Antarctic Ecoregion.
	Abyss > 3500 m	55,610 km ²	Large homogeneous level or gentle sloping region. Mostly soft substrate with limited evidence of mixed substratum from biotic data. Extends along the southern boundary of the ecoregion.
	Shallow Seamount 90-250 m	6,951 km ²	Four shallow seamounts that rise from Lower Slope to < 250 m from surface. Hard substrate provides habitat distinct from surrounding deep ecosystems.
	Seamount 250-3500 m	3,949 km ²	Seven seamounts with hard substrate, most of which are associated with the SWIR.
	Shallow Spreading Ridge 250-500 m	272 km ²	Three isolated peaks on the ridges of the SWIR comprised of hard substrate.
	Upper Spreading Ridge 500-1000 m	874 km ²	Multiple (14) scattered, small isolated peaks on the ridges of the SWIR comprised of hard substrate.
	Mid Spreading Ridge 1000-1800 m	14,852 km ²	Hard slopes of increased gradient associated with SWIR. Includes the shallowest parts of large areas of the SWIR.
	Lower Spreading Ridge 1800-3500 m	56,943 km ²	Largest and deepest part of the SWIR slope comprised of hard substrate. Extends across the PEI Sub-Antarctic ecoregion and beyond the sub-Antarctic territory to the north-east and south-west.

Lower Rift Valleys and Troughs 1800-3500 m	2,830 km ²	Long narrow, closed valleys and depressions within the surrounding Lower Slope Spreading Ridge comprised of soft substrate.
Deep Rift Valleys and Troughs > 3500 m	12,822 km ²	Two extensive elongated rift valleys bisect the western part of the SWIR. Mostly soft substrate. This is the deepest ecosystem type in the broader spreading ridge feature.
Shallow Plateau 90-500 m	1,805 km ²	Shallow plateau known as Galieni bank. This is the only feature of its kind in the sub-Antarctic territory and may be unique to the broader Sub-Antarctic region.
Mid Plateau 1000-1800 m	15,248 km ²	Part of larger plateau with increasing gradient but sometimes flattens out. Comprised of soft and mixed substrate.
Lower Plateau 1800-3500 m	36,622 km ²	Most extensive part of eastern plateau. Gentle slope with soft and mixed substrate rising from surrounding deep ocean floor. Likely found beyond sub-Antarctic territory.
PEI POLAR FRONT ECOREGION		
Seamount 250-3500 m	1,760 km ²	Two isolated seamounts comprised of hard substrate that rise from the Abyss.
Abyss > 3500 m	155,422 km ²	Deep plains of soft substrate that form the largest continuous area of abyssal habitat in the sub-Antarctic territory. Part of the much larger Atlantic Basin that extends beyond sub-Antarctic territory. Pelagic environment strongly influenced by the productive Polar Frontal Zone.
OB AND LENA POLAR FRONT ECOREGION		
Abyss > 3500 m	4,072 km ²	Soft abyssal plain forming a peripheral part of the major Ob and Lena seamount complex to the east of the sub-Antarctic territory. The most southerly ecosystem type.

3. ECOSYSTEM ASSESSMENTS

Skowno, A., Sink, K.L., Holness, S., Fairweather, T., von der Meden, C., Adams, R. and van der Merwe, S. 2019. '3: Ecosystem Assessments', in *National Biodiversity Assessment 2018 Technical Report Volume 6: sub-Antarctic Territory*. Whitehead, T.O., Von der Meden, C., Skowno, A.L., Sink, K.L., van der Merwe, S., Adams, R. and Holness, S. (eds.). South African National Biodiversity Institute, Pretoria.



A volcanic pinnacle emerges from the ocean next to Prince Edward Island. Photo: Peter Ryan.

Introduction

This chapter assesses **Threat Status** and **Protection Level** of South Africa's sub-Antarctic ecosystems. This is the first national assessment to apply headline ecosystem indicators to the sub-Antarctic territory. Both Threat Status and Protection Level were assessed for marine ecosystem types while only Protection Level was assessed for terrestrial ecosystem types as there was insufficient information to assess Threat Status.

The IUCN Red List Framework

South Africa is one of several countries to independently develop indicators of ecosystem threat prior to the IUCN Red List of Ecosystems (RLE) (Botts *et al.* in review, Keith *et al.* 2013) (www.iucnrle.org). The IUCN RLE aims to meet a recognised need for an indicator similar to the IUCN Red List of Species that could identify risk for higher-levels of biodiversity organisation such as ecological communities (Noss 1990, Rodríguez *et al.* 2011, Keith *et al.* 2013, Bland *et al.* 2017a). The IUCN Red List of Ecosystems is a framework for assessing the risks to ecosystems and identifying where ecosystems are threatened (Rodríguez *et al.* 2011). Using the familiar categories from the Red List of Species (Figure 35), and based on a set of criteria and thresholds developed collaboratively since 2008, the IUCN RLE was established to ensure that the assessment methods: (i) can be applied systematically across realms and geographic areas; (ii) are transparent and scientifically rigorous; (iii) are comparable and repeatable; (iv) can be easily understood by policy makers and the general public; and (v) complement the IUCN Red List of Threatened Species framework (Rodríguez *et al.* 2011, Keith *et al.* 2013, Bland *et al.* 2017a).

The key concepts and definitions underpinning the RLE have been documented in a number of international journal publications, notably (Nicholson *et al.* 2009), (Rodríguez *et al.* 2011), (Keith *et al.* 2013, 2015), (Bland *et al.* 2017b, Bland *et al.* 2018). There is growing uptake of the IUCN RLE standards (Bland *et al.* 2017a) with numerous sub-global assessments adopting the RLE approach (including North America, Philippines, Australia, Colombia, France, Finland). Ultimately, national and other sub-global assessments undertaken using these international standards will contribute towards establishing a global database of threatened ecosystems equivalent to the global Red List of Species.

The goal of the IUCN RLE is to identify ecosystems that are at risk of losing their constituent biodiversity. While there is substantial evidence that ecosystem function and services are linked with biodiversity (Bland *et al.* 2017a), the relationships between these three facets of ecosystems can be complex. Consequently, the RLE focusses specifically on risks to biodiversity (Keith *et al.* 2013). The RLE requires consistent and clearly defined units of assessment (i.e. ecosystem types) that can be delineated spatially, while at the same time the RLE needs to be able to effectively assess risks across widely contrasting ecosystems (Keith *et al.* 2013), such as those in the sub-Antarctic compared to mainland South Africa. Vegetation types, in particular, have been suggested as appropriate and consistent units that represent biodiversity and communities at an appropriate scale for use in the RLE (Keith *et al.* 2013, Boitani *et al.* 2015). The RLE framework uses the concept of ecosystem collapse as the 'end point' of ecosystem decline, this is equivalent to species extinction in the RLS, and is defined operationally as a 'transformation of identity, loss of defining abiotic or biotic features and characteristic native biota are no longer sustained' (Keith *et al.* 2013).

Criteria and Thresholds

The risk assessment model for the IUCN RLE is illustrated schematically in Figure 27A. Declining distributions (Figure 27A-A) and restricted distributions (Figure 27B-A) are considered distributional symptoms of decline; and degradation of abiotic environment (Figure 27A-C) and altered biotic function (Figure 27A-D) are considered functional symptoms of decline. It is possible for these mechanisms to interact and produce

additional symptoms of decline (Keith *et al.* 2013). The mechanisms in the conceptual model translate into five rule-based criteria with thresholds for the distributional and functional symptoms.

The South African List of Threatened Ecosystems was conceptualised as a national indicator of ecosystem conservation status in the early 2000s. From its early applications as a project-based indicator (ref), it progressed into a legislated national listing of threatened terrestrial ecosystems (RSA 2011). South Africa has been reporting on the Threat Status of its ecosystems for more than a decade, and using this information to focus scarce resources on conservation priorities through a wide range of government policies (Driver *et al.* 2004, 2012). Assessment methods and implications of the shift to the IUCN RLE approach are best understood in the mainland terrestrial realm where an established and stable National Vegetation Map is the foundation of the assessment (Skowno *et al.* 2019 realm report). Assessments in the sub-Antarctic territory are less mature, and despite advances in marine ecosystem classification and mapping, there has been limited monitoring in either marine or terrestrial environments to track changes and detect trends over time.

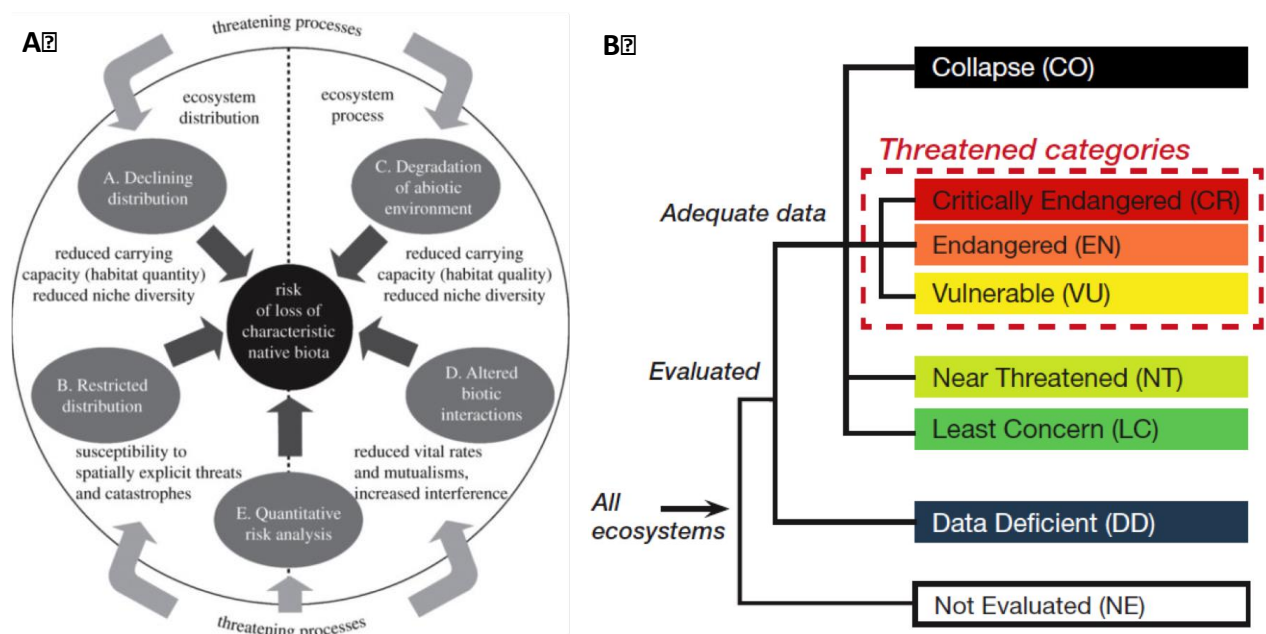


Figure 27. (A) IUCN RLE framework for assessing the risk of ecosystem collapse (Keith *et al.* 2013). (B) IUCN RLE threat categories, see glossary of terms of definitions (Bland *et al.* 2017a).

PEI Special Nature Reserve

South Africa's southernmost territories were declared a Special Nature Reserve in terms of the Environment Conservation Act (No. 73 of 1989), which was superseded by the National Environmental Management: Protected Areas Act (No. 57 of 2003; NEMPA). The islands enjoy the highest level of protection afforded to any natural area under South African law, with activities restricted to scientific research, environmental monitoring and conservation management. The islands are also recognised as a RAMSAR Wetland of International Importance and the Special Nature Reserve ensures the wetlands and rivers at the PEIs are protected.

PEI Marine Protected Area

The Exclusive Economic Zone (EEZ) extends 200 nautical miles from the PEIs and covers 474 897 km². The Prince Edward Islands Marine Protected Area (PEIs MPA) was proclaimed in April 2013, which represents 36% of EEZ (169 966 km²) and makes it South Africa's largest MPA. The MPA was designed to protect unique

habitats, reduce fishing pressure on populations of Patagonian Toothfish (*Dissostichus eleginoides*) to allow for recovery of stocks, and limit bycatch associated with the fishery (particularly albatrosses and petrels). Although the original design of the PEI Marine Protected Area recommended the exclusion of fishing for Patagonian Toothfish from the four restricted zones, toothfish longlining is permitted in three of the four restricted zones (Lombard *et al.* 2007). The MPA currently consists of a core sanctuary zone around the islands and one restricted zone (zone AB) in which no fishing is permitted (together making up 6% of the EEZ), three restricted zones where controlled scientific fishing of Patagonian Toothfish is allowed to monitor recovery (8% of the EEZ), and a large controlled zone in which permitted vessels may fish (26% of the EEZ) (Figure 28).

The PEIs lie within the larger Southern Ocean where 95.5% of the marine regions of sub-Antarctic islands are within MPAs (WDPA database) and their position in the Southwest Indian Ocean places them within a region managed by the Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR) (Nel and Ouardien 2008). CCAMLR has conservation measures in place to avoid significant adverse impacts on Vulnerable Marine Ecosystems (VME) from bottom fishing activities, but there are no risk areas (> 10 VME taxa) recorded at the PEIs that do not permit fishing. Prior to the declaration of the PEIs MPA, unrestricted fishing was allowed to occur in geomorphic areas where VMEs occur, however, fishing in these areas is now restricted.

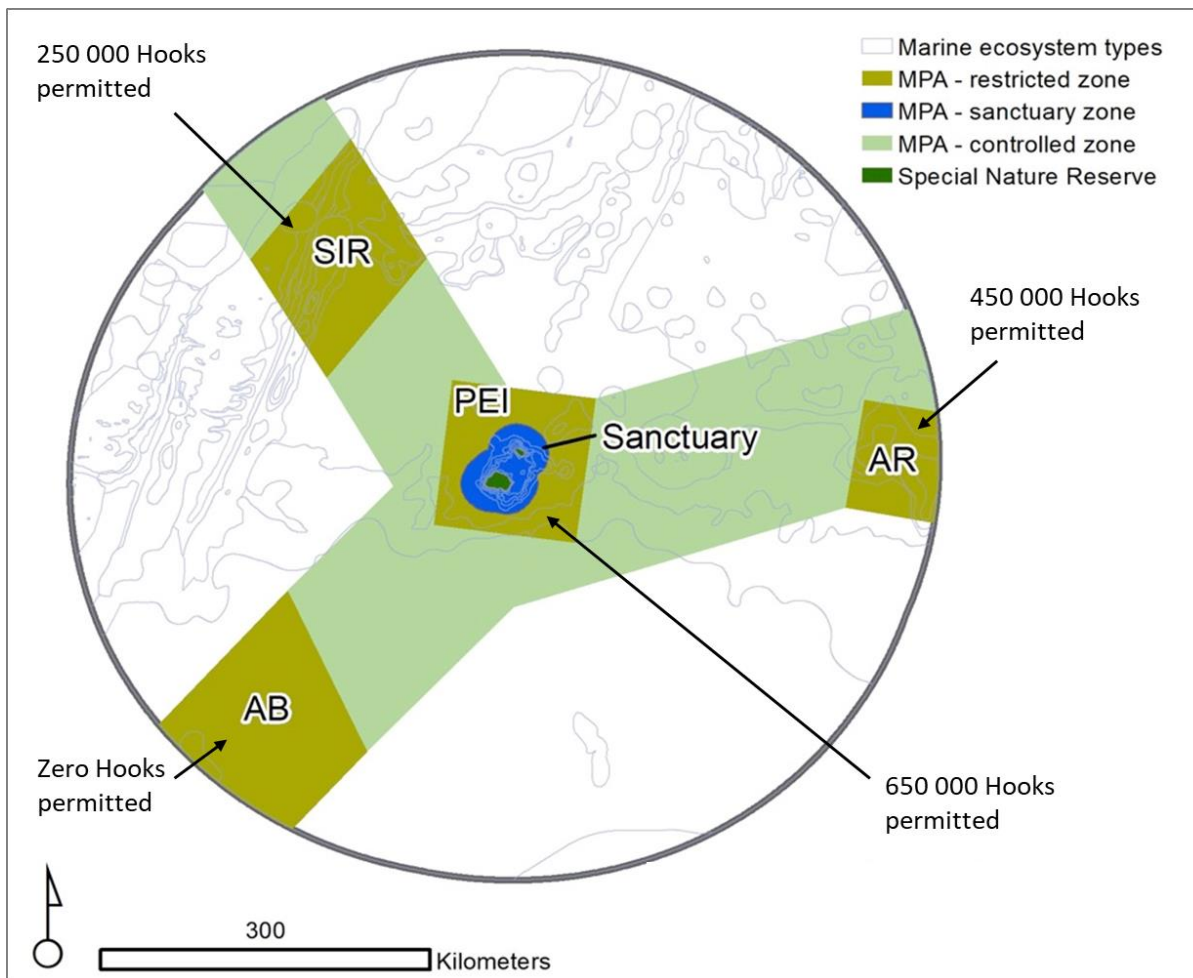


Figure 28. Map showing MPA zonation within the PEI EEZ. Sanctuary zone around the Islands – no access or resource use. Four Restricted zones where limited scientific fishing to monitor recovery of Patagonian Toothfish is permitted. One Controlled zone – only vessels with a permit issued by DEFF may fish for Patagonian Toothfish using only longlines and with observer on board.

Table 10. Total number of fishing hooks permitted in each of the restricted zones in the PEI MPA and the ecosystem types represented within each zone. A total overall annual limit of 1 044 213 hooks was set for all restricted areas combined. Ecosystem types are listed alongside their Threat Status categories Vulnerable (VU) and Endangered (EN).

Restricted area	Annual allowable maximum fishing effort (per year)	Ecosystem types represented
Prince Edward Island Restricted Zone (PEI)	650 000 hooks	sub-Antarctic shallow seamount (VU), sub-Antarctic lower slope, sub-Antarctic abyss, sub-Antarctic inner shelf, sub-Antarctic mid slope (VU), sub-Antarctic upper slope (VU), sub-Antarctic shelf edge (VU), sub-Antarctic outer shelf, Polar Front abyss.
Africana II Rise Restricted Zone (AR)	450 000 hooks	sub-Antarctic lower plateau, sub-Antarctic mid plateau, sub-Antarctic shallow plateau, sub-Antarctic Lower slope
Southwest Indian Ridge Restricted zone (SIR)	250 000 hooks	sub-Antarctic lower slope, sub-Antarctic lower spreading ridge, sub-Antarctic mid spreading ridge, sub-Antarctic upper spreading ridge (VU), sub-Antarctic shallow spreading ridge (EN), sub-Antarctic seamount, sub-Antarctic deep rift valleys and troughs.
Abyss Restricted zone (AB)	Zero Hooks (i.e. No Fishing permitted)	Polar Front abyss, Polar Front seamount.
Sanctuary area within 12nm of Marion and Prince Edward Islands	No fishing permitted, access limited to government vessels, research vessels, anchorage (in designated areas) and transit (with fish gear stowed).	sub-Antarctic shallow seamount (VU), sub-Antarctic lower slope, sub-Antarctic abyss, sub-Antarctic inner shelf, sub-Antarctic mid slope (VU), sub-Antarctic upper slope (VU), sub-Antarctic shelf edge (VU), sub-Antarctic outer shelf.

Pressures in the sub-Antarctic

Activities at the PEIs and in the surrounding ocean are restricted to commercial fishing, research, and conservation management. Terrestrial ecosystems are free from pressures typically found on the mainland, but are threatened by invasive species and climate change. Data from these threats are not yet available to systematically apply in ecosystem threat assessments but they are discussed in Chapters 4 and 5, respectively.

The only pressure data available for this first assessment of Ecosystem Threat Status in South Africa's sub-Antarctic territory are from the commercial fishery for Patagonian Toothfish (see Box 1 for more details). This resource was previously considered over-exploited (Brandão *et al.* 2002), but current stock status and fishing pressure are both considered optimal despite some uncertainties in Catch Per Unit Effort relating to predation, changes in gear, the stock-recruitment relationship and pre-exploitation baselines (DAFF 2016). The fishery has other ecological interactions and potential impacts. These include bycatch of non-target species (CCAMLR 2017), seabird mortality associated with hooks and longlines (Ryan and Boix-hinzen 1999, Tasker *et al.* 2000, Nel *et al.* 2002, Moreno *et al.* 2008, Suazo *et al.* 2014), entanglement of large marine mammals (Gilman *et al.* 2006, CCAMLR 2014, 2017), and the removal of epibenthic habitat-forming species in Vulnerable Marine Ecosystems (VMEs) (Barnette 2001, WWF 2010).

Many fishing areas overlap with geomorphic features where VMEs occur as can be seen in the VME distribution map (Figure 22) and there is concern that fishing activities may severely damage these areas. Although research on benthic habitats at the PEIs is limited (Branch *et al.* 1993, Von der Meden *et al.* 2017), the removal of slow-growing habitat-forming species may result in loss of benthic diversity, reducing important food sources for higher trophic levels and leading to trophic collapse (Perissinotto and McQuaid 1990). Seabird bycatch is still a concern, however, the number of seabirds caught has been greatly reduced largely due to the adoption of trotlines (Moreno *et al.* 2008). Roughly 0.19 birds were killed per thousand

hooks in the 1996/1997 season, which decreased to 0.001 birds killed in 2001/2002 (Nel *et al.* 2002, Moreno *et al.* 2008). It is impossible to quantify the long-term cumulative impact of the Patagonian Toothfish fishery on seabirds as these were not reported by IUU fisheries (Nel and Taylor 2003). Bycatch of non-target species has been within CCAMLR limits, with 7 to 28 t of rattails *Macrourus* spp. and 3 t of skates *Rajidae* caught by the legal fishery since 2010 (DAFF 2016). Entanglement of cetaceans is possible as they often approach fishing lines to steal fish (Durholtz 2018), however, no damaged fish have been caught in hauls since 2002 (Durholtz 2018) and no cetacean deaths have been reported in the last 10 years (CCAMLR 2017). There are also no reported seabird mortalities in the last three years (DAFF 2016).

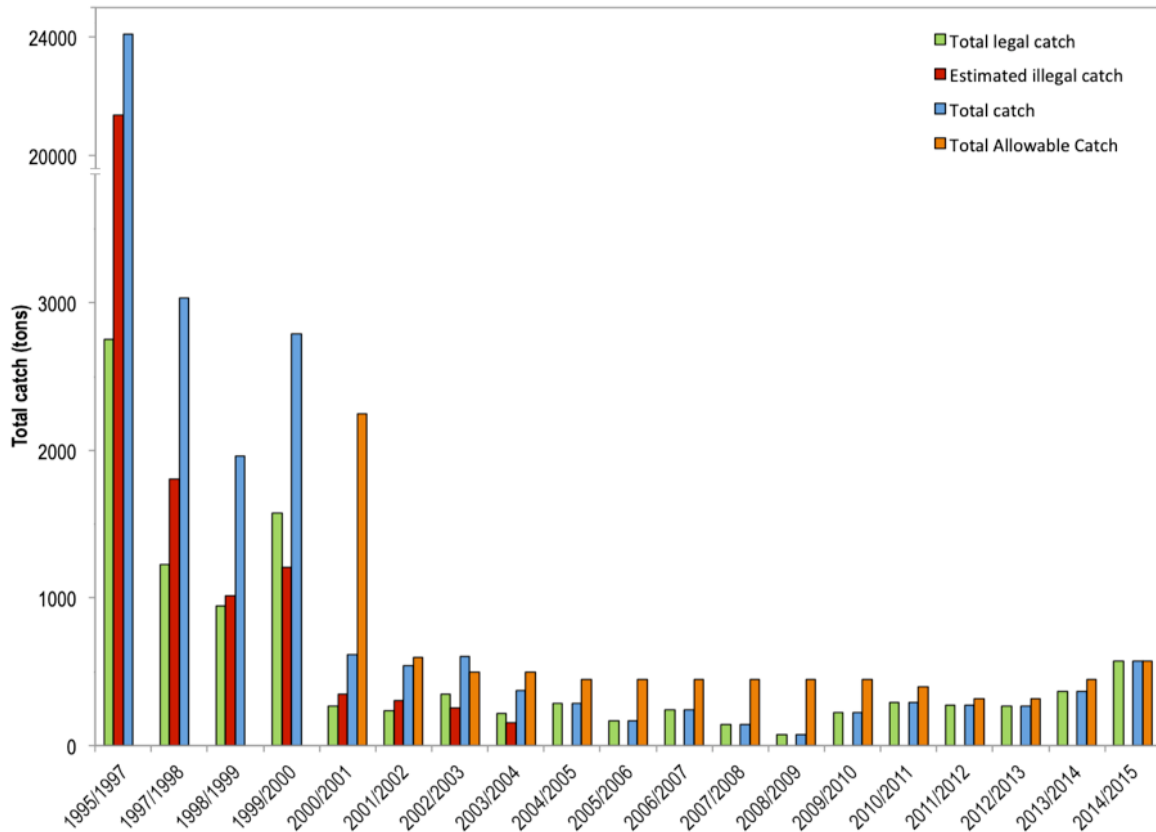


Figure 29. Total legal catch, estimated illegal catch and total catch of Patagonian Toothfish compared to the total allowable catch per fishing season. Data from DAFF (2016).



Figure 30. The commercial fishery for Patagonian Toothfish is a pressure on marine ecosystems in South Africa's sub-Antarctic territory, with direct impacts on toothfish and indirect impacts on seabed habitats and seabirds such as albatrosses and petrels that scavenge behind longlining vessels. Photos: Alistair Burls (CAPmarine), Jim Enticott.

Box 1: The history the Patagonian Toothfish Fishery in South Africa's sub-Antarctic territory

Patagonian Toothfish (*Dissostichus eleginoides*) are high-value Nototheniid fishes that occur in deep waters (70-1600 m) near seamounts and sub-Antarctic islands. These resident, slow growing fish only reach maturity after 9-10 years and at a size of nearly one metre (DAFF 2016), with the largest reported fish being 2.3 m (Collins *et al.* 2010). This makes toothfish extremely vulnerable to over-exploitation, which is what happened in South Africa's sub-Antarctic territory.

Extensive fishing for Patagonian Toothfish started in the 1990s when high numbers of Illegal, Unreported and Unregulated (IUU) fishing vessels capitalized on the lack of sanctioned fishing vessels in the vicinity of the PEIs (Nel 2008, Brandão and Butterworth 2009). While neighbouring islands had the capacity to manage their EEZ, South Africa's limitations to patrol the



remote region resulted in intensive over-exploitation by IUU fishing vessels and near collapse of Toothfish stocks (Japp *et al.* 2008). Illegal catches of Toothfish were estimated at more than 21,000 t between 1995 and 1997 (DAFF 2016). In 1996, sanctions were put in place to curb and monitor catches, but IUU fishing continued until 2004, although at much lower levels (Figure 29). It was estimated that Toothfish had been so heavily exploited in those ten years that the spawning biomass was only a few percent of pre-exploitation levels (Brandão *et al.* 2002). After a 10-year experimental period, the first commercial fishing in the EEZ started in 2006, whereafter the five long-term rights holders reduced fishing effort due to changes in gear, consortiums and vessel numbers (Nel 2008, DAFF 2016).

Currently, only two permit holders are in operation, with most of the fishing activity concentrated to the north and east of the PEIs, however, no fishing is permitted within 22 km of the islands (Lombard 2008). Recent stock assessments estimate toothfish are 53-60% depleted, but this is complicated by various changes to the types of gear employed (DAFF 2016). South Africa's role in the Convention of Antarctic Marine Living Resources (CCAMLR) requires each vessel to have an independent fisheries observer on-board to monitor best practice (Nel 2008). Fishing was initially conducted seasonally but is now permitted year-round to discourage IUU fishing vessels (Nel 2008). It is unknown the extent to which IUU fishing still occurs but regional management bodies such as CCAMLR consider it a serious threat to the sustainability of marine living resources (Miller 2007). It is imperative that South Africa mobilise monitoring and research bodies as well collaborate with neighbouring nations to exclude this practice from South Africa's sub-Antarctic territorial waters.

Input data***Ecosystem classification maps***

The key input dataset for the terrestrial ecosystem assessment was the National Vegetation Map 2018. This digital map delineates five vegetation types (equivalent to ecosystem types) within the PEIs (Smith and Mucina 2006). Studies are underway to revisit and potentially improve the classification and delineation of terrestrial ecosystem types at a finer scale that better represents the complex mosaic of plant communities. Since the terrestrial ecosystem types at Marion - and Prince Edward Island may occur at other sub-Antarctic

islands, regional understanding of these ecosystem types will require additional collaborative research. The first detailed map of the marine ecosystem types in South Africa's sub-Antarctic Territory was produced as part of the NBA 2018 (von der Meden *et al.* 2019). The map was based on extensive research, consolidating historical and current information on regional biogeographic pattern, bathymetry and benthic ecosystems. The ecosystem types are nested within broader regional ecoregions and some extend beyond national jurisdiction. The 29 marine ecosystem types can be classified into nine functional groups. Increased investment in research has improved the marine ecosystem classification and map of the region.

Pressure data

While the terrestrial ecosystems of the PEIs are free from the typical direct pressures of mainland South Africa (e.g. land clearing for croplands), these ecosystems are subject to substantial degradation from biological invasions and climate change. As a result of research activities, Marion island is also subject to human disturbances like trampling and erosion associated with access pathways. Research is underway to comprehensively evaluate and map these pressures, and a revised regional assessment of terrestrial ecosystems will be possible in the near future. Pressure from the commercial Patagonian Toothfish fishery was the only pressure that could be mapped for marine ecosystems within the sub-Antarctic territory. It was mapped using fishing effort data (total number of hooks set) available from 1997 until 2016 using a kernel density approach (95% value) (Figure 31).

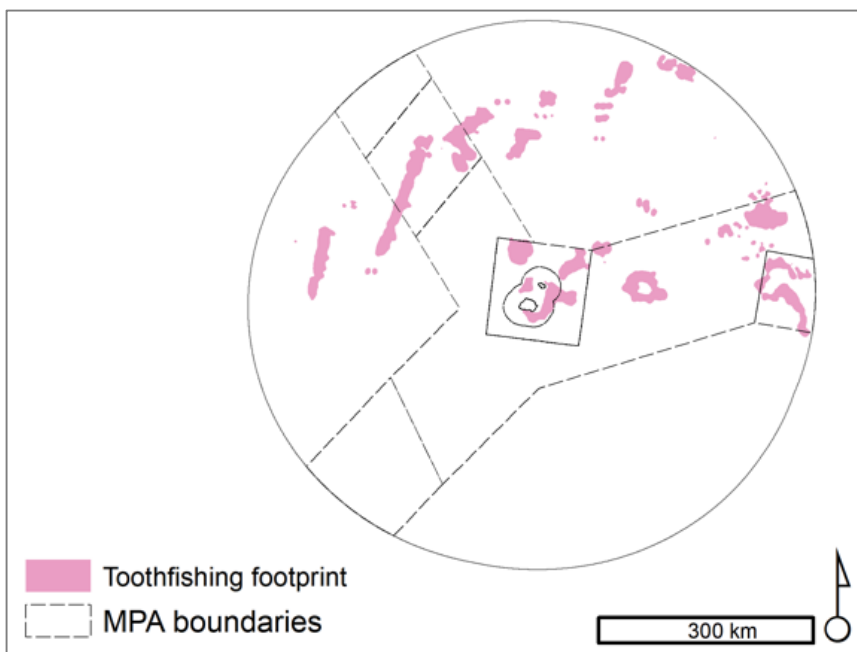


Figure 31. Patagonian Toothfish fishing footprint in relation to the PEI Marine Protected Area.

Catch and effort data for the Patagonian Toothfish fishery were provided to Capricorn Marine Environmental (CAPmarine) by the former Department of Agriculture Forestry and Fisheries. CAPmarine subsequently created GIS spatial files from 1996 (start of exploratory fishing) to 2016. Maps were constructed with a grid resolution of 10 by 10 minutes. The dataset did not define the years that data were collected. This meant that the most recent fishing impact was indistinguishable from that prior to the start of the regulated commercial fishery, however, CAPFISH reported that the highest fishing intensity occurred between the years 1996 to 2000. Pressure data from the fishery are likely to underestimate impacts, as it was not possible to quantify the impact of IUU fishing vessels on marine ecosystem. In addition, impacts on VMEs, the extent

and effects of cetacean entanglements and bycatch of non-target species and seabirds is not well understood.

Ecosystem Threat Status

Implementation of the IUCN Red List of Ecosystems

The Ecosystem Threat Status assessment for the five terrestrial PEI ecosystem types was hampered by the lack of appropriate data on ecological condition and, following the IUCN RLE guidelines, these ecosystems were assessed as Data Deficient. Research is underway to fill this gap by assessing the ecological condition of the ecosystem types. With biological invasion and climate change being the key threats (see Chapters 4 and 5), disruption of biological processes and ecosystem degradation is an increasing concern. There is a gap in our ability to understand thresholds of condition and there are challenges in measuring the subtler forms of habitat degradation. As a result, the level of modification of terrestrial and marine ecosystems may be underestimated. Better information on biotic disruptions (particularly by mice, invasive plants and invertebrates) and environmental degradation (climate change and human impacts) are required for a meaningful assessment. Consequently, a more comprehensive terrestrial ecosystem threat assessment may be conducted in the near future, which will be incorporated into the next NBA.

A first assessment of the sub-Antarctic's 29 marine ecosystem types was undertaken using a criterion aligned to the IUCN guidelines for red listing ecosystems (Bland *et al.* 2017 v1.1). The benefits of using the IUCN system included the strong scientific evidence base, recognition of the resulting RLE by the IUCN and alignment for with international conventions and assessment processes. Consequently, the NBA 2018 Marine Reference Group decided that an approach with greater alignment to the IUCN RLE approach should be adopted for the NBA 2018. The assessment results were based on IUCN Criteria C1 (recent ecosystem degradation; Table 11) as this was most relevant to the marine ecosystem assessment based on mapping of the Patagonian Toothfish fishery footprint. The impact of each pressure on each ecosystem type was weighted using the extent of ecosystem degradation and an ecosystem pressure matrix (Table 11). The extent of the fishing footprint was calculated for each ecosystem type, and the severity of the impact was estimated to be moderate throughout. Ecosystems with 80% or more of their extent within the fishing footprint were categorised as Endangered, those with 50% or more were categorised as Vulnerable, and those with less were considered Least Concern. At this stage, the presence and abundance of potential VME indicator species was not considered in the assessment of Threat Status.

Table 11. Criteria for the assessment of Ecosystem Threat Status.

C. Environmental degradation over ANY of the following time periods				
C1. The past 50 years. Based on change in an <u>abiotic</u> variable affecting a fraction of the extent of the ecosystem and with a relative severity, as indicated by the following table:	Extent (%)	Relative severity (%)		
		≥ 80	≥ 50	≥ 30
	≥ 80	CR	EN	VU
	≥ 50	EN	VU	
	≥ 30	VU		

Ecosystem Threat Status assessment results

All five terrestrial ecosystem types are categorised as Data Deficient (DD) based on the IUCN RLE guidelines (Table 12). Of the 29 marine ecosystem types described, six (21%) are threatened by historical or current fishing. Only one ecosystem type is considered Endangered (Figure 32), the PEI sub-Antarctic Shallow

Spreading Ridge, which has been fished over its entire extent. The five Vulnerable ecosystem types include the PEI Shelf Edge, Upper Slope and Mid Slope, which were threatened by historical fishing within the 12 nautical mile territorial sea (now a sanctuary zone of the MPA). More than 65% of the PEI sub-Antarctic Shallow Seamount and Upper Spreading Ridge are fished, making them Vulnerable. The remaining marine ecosystem types have been fished over less than half of their extent and are considered Least Concern at this stage (Figure 32). Risks from climate change and biological invasions need to be incorporated in future assessments that adopt a regional rather than a national approach.

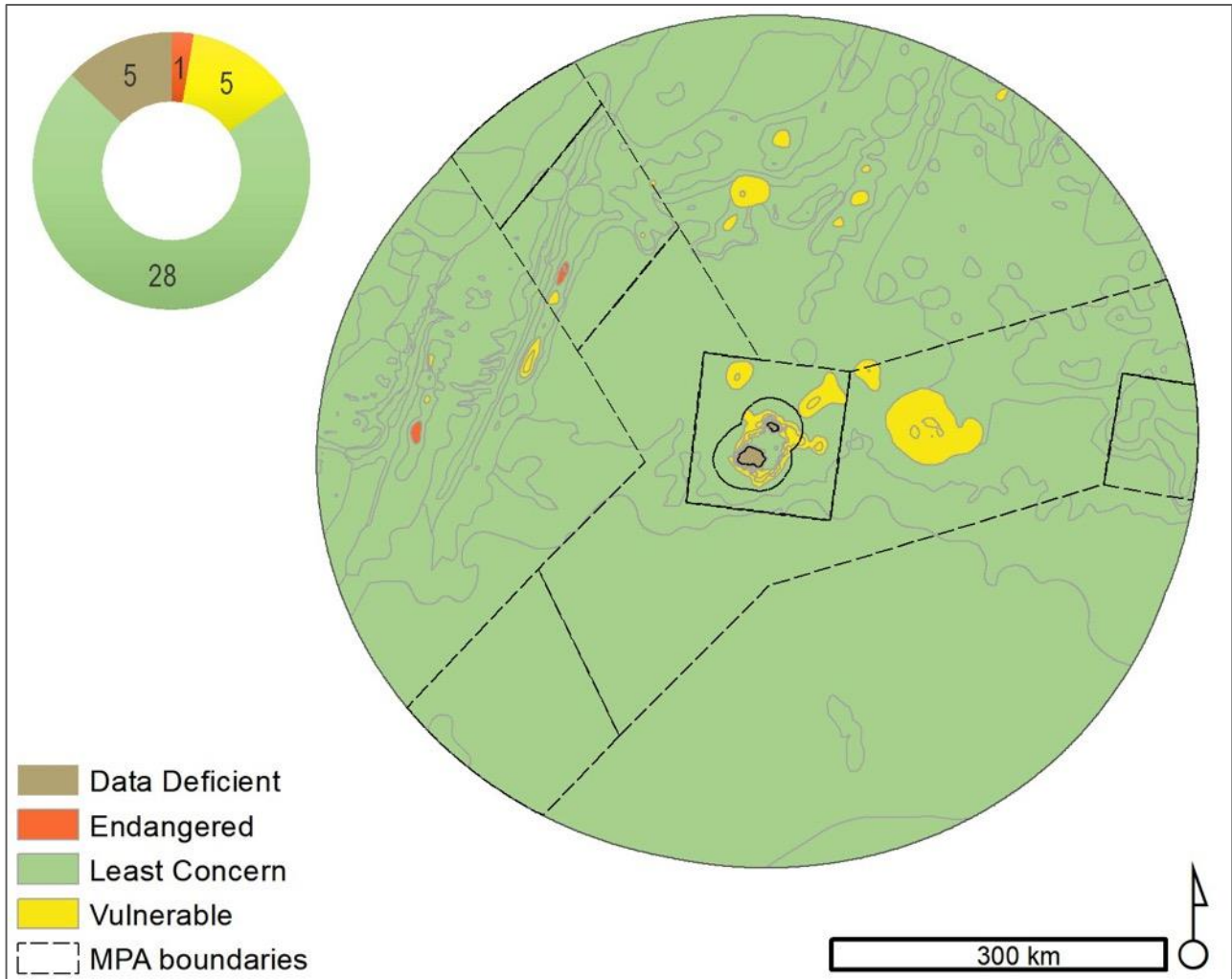


Figure 32. Distribution of threatened ecosystems at the Prince Edward Islands and surrounding Exclusive Economic Zone. The five terrestrial ecosystems are listed as Data Deficient and 6 of 29 marine types are threatened (see Table 13). The inset shows the number and proportion of ecosystems types in each IUCN RLE category.

Ecosystem Threat Status limitations

Three key challenges limit our ability to perform threat assessments for terrestrial ecosystems in the sub-Antarctic. Firstly, a key limitation is the lack of appropriate and readily available pressure and ecosystem condition data. The land cover change dataset used to calculate the ecological condition of the NBA Terrestrial Realm's ecosystems, could not be used for the PEIs, as the typical direct pressures of the mainland, such as croplands or built up areas, are not present on the islands. The land cover classes used for the mainland were therefore not appropriate for the PEIs. Furthermore, cloud-free satellite imagery of the islands is rare. The impacts of terrestrial alien invasive species and climate change (the two key threats at the PEIs) are increasingly well documented but ecosystem assessments require spatially explicit information on ecosystem condition, and this remains a challenge. Recent observations suggest a rapid change in plant

communities (e.g. Hedding and Greve 2018), however, data to support these observations are lacking. Without data on the level of modification of the ecological condition of ecosystems at temporal and spatial scales, terrestrial threat assessments will remain challenging. Secondly, the ecosystem types might extend beyond South African territory. These are national assessments and comprehensive regional assessments should remain the goal for all our sub-Antarctic ecosystem types in future. This highlights the opportunity for co-operation with international partners to determine the distribution and condition of the PEIs' terrestrial ecosystem types and species that could extend beyond South Africa's territory. Thirdly, the complex mosaic of plant communities on the islands poses a challenge in the classification and delineation of ecosystem types at appropriately fine scales that are still relevant for assessment.

There are three main limitations to this first marine ecosystem assessment for our sub-Antarctic territory relating to fishing impacts, other pressures and the regional extent of some ecosystem types. Firstly, our knowledge of the impacts of Toothfish fishing is poor with limited understanding of the ecosystem effects of removing this species or the extent of impacts on the seabed and other ecosystem components. The effect of fishing on ecosystem condition is not well understood and more work is needed to develop conceptual models for the ecosystem types in this region and advance the understanding of potential thresholds of collapse. A further challenge relating to fishing data is that existing data to reflect the patterns in toothfish fishing effort does not adequately reflect the considerable illegal fishing effort in the period between 1990 and 2004. Secondly, other key pressures, particularly climate change could not be considered at this stage due to insufficient spatial data. Lastly, several ecosystem types may extend beyond South Africa's territory in the Southern Ocean and may be best assessed with consideration of their full extent and ecosystem degradation across their range.

Ecosystem Protection Level assessment

Ecosystem Protection Level calculation method

Ecosystem Protection Level is an indicator that tracks how well represented an ecosystem type is in the protected area network. For the PEIs, Ecosystem Protection Level was computed by determining the proportion of each ecosystem type that falls within the protected area network. No ecosystem-specific biodiversity targets have been examined for ecosystem types at the PEIs and so a fixed biodiversity target of 20% protection was used. For a marine ecosystem type to qualify as Well Protected, at least 20% of the ecosystem type needed to be within the portion of MPA in which no fishing is permitted (12 nautical mile sanctuary and restricted zone AB). If this rule was not met, the ecosystem was downgraded to Moderately Protected. Table 12 describes criteria for protection status.

Table 12. Protection Level descriptions of ecosystem types. Target used was $\geq 20\%$ of ecosystem type protected.

Protection Status	Description
Well Protected	Extent protected exceeds the biodiversity target (i.e. $>20\%$ of ecosystem type is protected) and fishing is excluded from 20% of the ecosystem type
Moderately Protected	$>50-99\%$ of target (10-20% of ecosystem type) in the Protected Area Network
Poorly Protected	$>5-49\%$ of target (1-10% of ecosystem type) in the Protected Area Network
Not Protected	$<5\%$ of target ($<1\%$ of ecosystem type) in the Protected Area Network

Ecosystem Protection Level results

All five terrestrial ecosystem types were categorised as Well Protected (Figure 33, Table 13). Overall, 86% of marine ecosystem types are afforded some protection by the MPA network. Ten marine ecosystem types are Well Protected (35%), 14 are Moderately Protected (48%), one is Poorly Protected (4%) and four are Not Protected (14%).

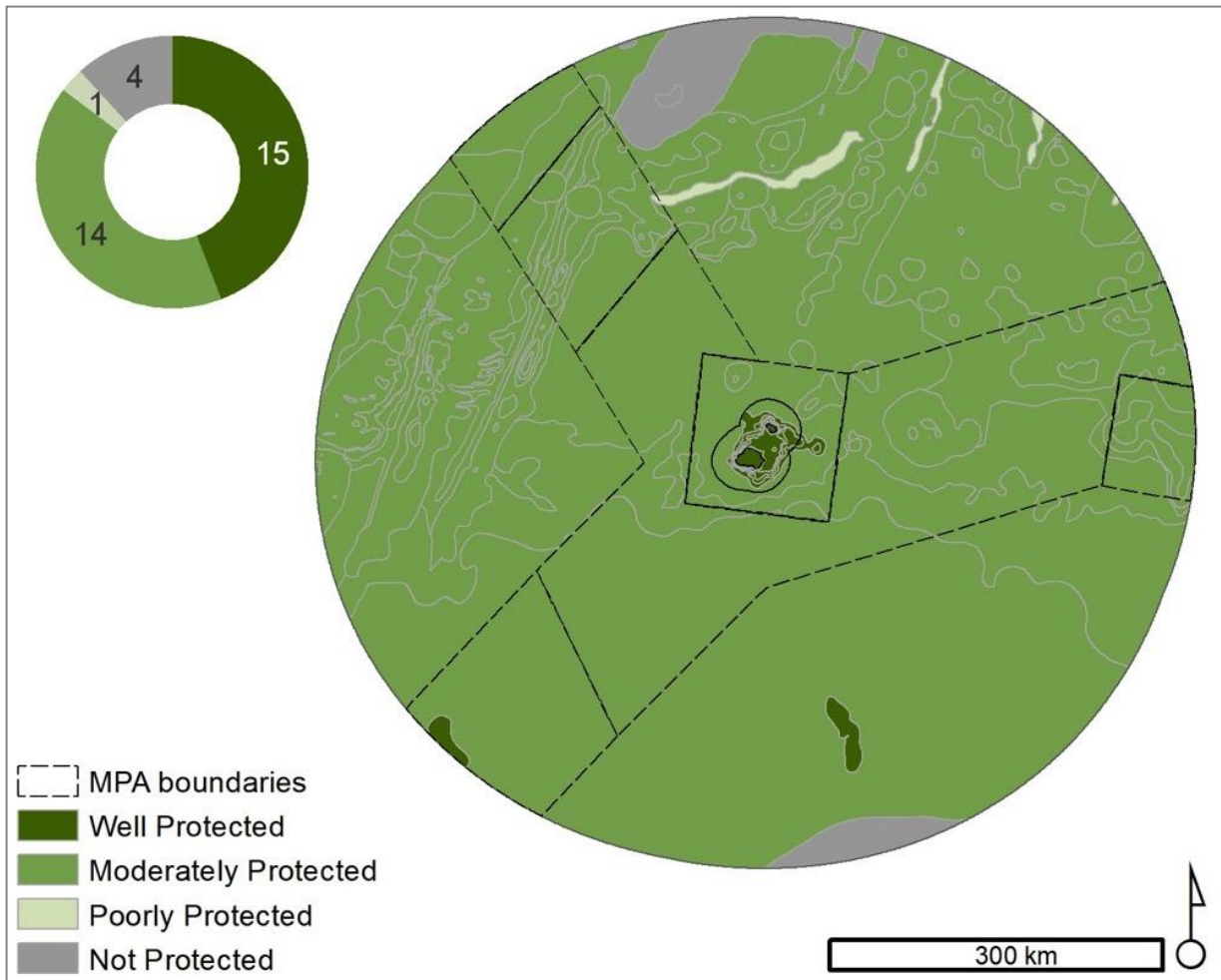


Figure 33. Ecosystem Protection Level map of the Prince Edward Islands (PEIs) and surrounding Exclusive Economic Zone (EEZ). The inset shows the number and proportion of ecosystems types in each category.

Ecosystem Protection Level limitations

As with the Ecosystem Threat Status assessment, this is the first assessment of Protection Level and does not yet consider the regional or global extent of ecosystem types, however this is an accurate indicator for the South African territory. Better data on ecological condition and spatial extent are needed to improve future Protection Level assessments.

Table 13. The Threat Status (DD is Data Deficient, LC is Least Concern, VU is Vulnerable, EN is Endangered) and Protection Level (NP is Not Protected, PP is Poorly Protected, MP is Moderately Protected, WP is Well Protected) of each terrestrial vegetation and marine ecosystem type.

	ECOSYSTEM TYPE	Threat Status	Protection Level
Terrestrial Vegetation Types	sub-Antarctic Coastal Vegetation	DD	WP
	sub-Antarctic Mire Slope Vegetation	DD	WP
	sub-Antarctic Fellfield	DD	WP
	sub-Antarctic Cinder Cones	DD	WP
	sub-Antarctic Polar Desert	DD	WP
Marine Ecosystem Types	Ob and Lena Polar Front Abyss	LC	NP
	Prince Edward Island Polar front Abyss	LC	MP
	Prince Edward Island Polar Front Seamount	LC	WP
	PEI sub-Antarctic Abyss	LC	MP
	PEI sub-Antarctic Deep Rift Valleys and Troughs	LC	MP
	PEI sub-Antarctic Exposed Cliff and Broken Shore	LC	WP
	PEI sub-Antarctic Highly Exposed Cliff and Broken Shore	LC	WP
	PEI sub-Antarctic Inner Shelf	LC	WP
	PEI sub-Antarctic Least Exposed Cliff and Broken Shore	LC	WP
	PEI sub-Antarctic Least Exposed Mixed Shore	LC	WP
	PEI sub-Antarctic Lower Plateau	LC	MP
	PEI sub-Antarctic Lower Rift Valleys and troughs	LC	PP
	PEI sub-Antarctic Lower Slope	LC	MP
	PEI sub-Antarctic Lower Spreading Ridge	LC	MP
	PEI sub-Antarctic Mid Plateau	LC	MP
	PEI sub-Antarctic mid slope	VU	WP
	PEI sub-Antarctic Mid Spreading Ridge	LC	MP
	PEI Sub-Antarctic Outer Shelf	LC	WP
	PEI Sub-Antarctic Seamount	LC	MP
	PEI sub-Antarctic Shallow Plateau	LC	MP
	PEI sub-Antarctic Shallow Seamount	VU	MP
	PEI sub-Antarctic Shallow Spreading ridge	EN	MP
	PEI sub-Antarctic Shelf Edge	VU	WP
	PEI sub-Antarctic Upper Slope	VU	WP
	PEI sub-Antarctic Upper Spreading Ridge	VU	MP
	PEI Temperate Abyss	LC	MP
	PEI Temperate Lower Slope	LC	NP
	PEI Temperate Mid Slope	LC	NP
	PEI Temperate Seamount	LC	NP

Box 2: Threat status of species in the sub-Antarctic

The assessment of species in the sub-Antarctic has only been conducted for prominent seabirds and marine mammals at the Prince Edward Islands (PEIs). The marine mammals include the Southern Elephant Seal (*Mirounga leonine*, NT), the Antarctic Fur Seal (*Arctocephalus gazella*, LC), the sub-Antarctic Fur Seal (*Arctocephalus tropicalis*, LC), and Orca (*Orcinus orca*, DD). As many of the seabirds also frequent waters near mainland South Africa, these assessments were included in the Marine realm report (Sink *et al.* 2019). In summary, there are 28 Threatened or Near Threatened bird species breeding at the PEIs that are Taxa of Conservation Concern (TOCC). These include the endemic Lesser Sheathbill (*Chionis minor*, NT), the Crozet Shag (*Phalacrocorax melanogenis*, CR), Macaroni Penguin (*Eudyptes chrysolophus*, VU), Eastern Rockhopper Penguin (*Eudyptes chrysocome filholi*, EN), Wandering Albatross (*Diomedea exulans*, VU), Sooty Albatross (*Phoebastria fusca*, EN), Indian Yellow-nosed Albatross (*Thalassarche carteri*, EN) and the Grey-headed Albatross (*Thalassarche chrysostoma*, EN).



■ Critically Endangered ■ Endangered ■ Vulnerable ■ Near Threatened

All three seal species at the PEIs are considered to be Least Concern. Species assessments have not been conducted for other groups, as many taxa occur beyond the PEIs and limited data are available from other regions to conduct species threat assessments. Many plant and invertebrate species, such as the Kerguelen Cabbage (*Pringlea antiscorbutica*), are endemic to the sub-Antarctic ecoregion, emphasising the need for species assessments as a conservation priority. Future species assessments will require data from entire species' distributions to assess Threat Status. While the limited evidence suggests that genetic diversity is surprisingly high in the terrestrial ecosystems of the PEIs (Ansorge *et al.* 2017) data limitations are a challenge in assessing genetic diversity.

4. THREATS IN THE SUB-ANTARCTIC I – ALIEN AND INVASIVE SPECIES

van der Merwe, S., Greve, M., von der Meden, C. and Adams, R. 2019. '4: Threats in the sub-Antarctic – Alien and Invasive Species', in *National Biodiversity Assessment 2018 Technical Report Volume 6: sub-Antarctic Territory*. Whitehead, T.O., Von der Meden, C., Skowno, A.L., Sink, K.L., van der Merwe, S., Adams, R. and Holness, S. (eds.). South African National Biodiversity Institute, Pretoria.

v



A juvenile Grey-headed Albatross that has been scalped by an invasive House Mouse. Photo: Peter Ryan.

Introduction

The terrestrial and marine ecosystems of the Prince Edward Islands (PEIs) are well conserved and in considerably more natural condition than the ecosystems on and around mainland South Africa. However, the PEIs face pressures from an increasing range and intensity of direct human activities and through indirect disruption of biotic processes. The greatest biotic disruption to terrestrial ecosystems in the sub-Antarctic is from alien⁷ invasive species (Gremmen and Smith 1999, Frenot *et al.* 2005). Islands are particularly susceptible to alien species because their geographical isolation often distances them from colonising populations and restricts the immigration of new species, resulting in unfilled ecological niches (Russell *et al.* 2017). Consequently, native species often evolve with none to few competitors or predators, making them vulnerable to the impacts of new non-native species.

This chapter summarises available information on alien species at the PEIs, focussing on the species with the highest impact on native biota. At the PEIs, there are 46 alien terrestrial species, including 27 invertebrates, one vertebrate, one fungus and 17 plant species (many of which have become invasive) (Greve *et al.* 2017). The pathways and introduction vectors of alien species are fairly well understood, with most being introduced as a result of direct and accidental human activity (Greve *et al.* 2017). However, there is limited understanding of how invasive species impact the native biota and ecosystems at the PEIs (Greve *et al.* 2019). The few invasive species that have been studied have shown intermediate to severe impacts on native species, with the House Mouse having caused alarming decreases in abundance of the indigenous biota, especially invertebrates, impacting the terrestrial ecology (Chown and Smith 1993, Hänel and Chown 1998, Smith *et al.* 2002) and the breeding seabirds at the islands (McClelland *et al.* 2018). No other invasive species have comparable impacts to, or have been as well studied, as the House Mouse. The substantial increase in the mouse population has led to decreased abundance, biomass and densities of invertebrates, reduced plant seed stocks, and increased mortality of seabirds (Dilley *et al.* 2017, McClelland *et al.* 2018).

There are no records of alien marine species establishing within the sub-Antarctic region, including at the PEIs, despite their ability to disperse long distances (Greve *et al.* 2019). However, the deep-sea benthic ecosystems remain undersampled and therefore their status of biological invasion is not known (Greve *et al.* 2019). Invasive species introductions may increase with increased vessel traffic and the arrival of higher amounts of marine debris, especially under future climate scenarios (Frenot *et al.* 2005, McCarthy *et al.* 2019). Understanding invasion impacts under climate change has become a priority for the conservation of sub-Antarctic ecosystems, which are predicted to become more vulnerable to invasions with climate amelioration (Duffy *et al.* 2017, Steyn *et al.* 2017). The current climate at the PEIs is suitable for many known global invasive species (Duffy *et al.* 2017). Climate change may further increase climate suitability for invasive species and the subsequent risk of biological invasion to the sub-Antarctic and broader Antarctic regions (Chown *et al.* 2012, Duffy *et al.* 2017). Climate change may thus benefit alien species, aiding their spread and exacerbating their impacts.

Species lists

Alien species have been recorded at the Prince Edward Islands (Figure 34) from as early as 1804 (Cooper 2008). Most alien species were accidentally introduced (Greve *et al.* 2019), however, several species, such as pigs, goats, chickens, sheep and cats were purposefully brought to Marion Island for fresh food or as a control mechanism for mice, though these have since disappeared or been eradicated (Cooper 2008).

⁷ Alien species are non-native species, purposefully or accidentally introduced by humans to a new environment. Invasive species are those that are able to survive and reproduce in the new environment

Twenty nine alien species have become invasive, with many negatively impacting native species (Greve *et al.* 2017, McClelland *et al.* 2018), although some species have also had little impact (Gremmen *et al.* 1998), however, the impacts of most species remain under-studied (Greve *et al.* 2017) (Table 14). Prince Edward Island, where human activity is limited to visits every four years and for no more than a few days at a time, has only seven invasive species (Greve *et al.* 2017).

Table 14. Current terrestrial alien species at the Prince Edward Islands (extracted from Greve *et al.* (2017) Table 1). All species occur on Marion Island and species also present at Prince Edward Island are noted (*). Invasion Status was classified as either invasive or not, according to (Blackburn *et al.* 2011) (Appendix H). Categories D and E were considered “Invasive” and all others “Non-invasive”.

Family	Species	Common name	Invasion Status
Microbes			
Sclerotiniaceae	<i>Botryotinia fuckeliana</i> (de Bary) Whetzel		Non-invasive
Plants			
Potamogetonaceae	<i>Potamogeton nodosus</i> Poir.	Longleaf Pondweed	Non-invasive
Poaceae (Gramineae)	<i>Elymus repens</i> (L.) Gould	Couch Grass	Non-invasive
	<i>Agrostis castellana</i> Boiss. & Reut.	Highland Bentgrass	Non-invasive
	<i>Agrostis gigantea</i> Roth	Black Bentgrass or Red Top	Non-invasive
	<i>Agrostis stolonifera</i> L.	Creeping Bentgrass	Invasive
	<i>Festuca rubra</i> L.	Red Fescue	Non-invasive
	<i>Poa annua</i> L.*	Annual Bluegrass	Invasive
	<i>Poa pratensis</i> L.	Kentucky Bluegrass	Invasive
Juncaceae	<i>Juncus effusus</i> L.	Common Rush or Soft Rush	Non-invasive
	<i>Luzula cf. multiflora</i> (Ehrh) Lej.		Non-invasive
Caryophyllaceae	<i>Cerastium fontanum</i> Baumg.*	Mouse-ear Chickweed, Common Mouse-ear	Invasive
	<i>Sagina procumbens</i> L.*	Procumbent Pearlwort, Birdeye Pearlwort	Invasive
	<i>Stellaria media</i> (L.) Vill	Chickweed	Invasive
Polygonaceae	<i>Rumex acetosella</i> L.	Red Sorrel or Sheep's Sorrel	Invasive
Rosaceae	<i>Malus</i> spp.		Non-invasive
Thuidiaceae	<i>Thuidium delicatulum</i> (Hedw.) Schimp.	Delicate Fern Moss or Common Fern Moss	Non-invasive
Pottiaceae	<i>Leptodontium gemmascens</i> (Mitt.) Braithw.	Thatch Moss	Non-invasive
Invertebrates			
Porcellionidae	<i>Porcellio scaber</i> Latreille	Rough Woodlouse	Non-invasive
Digamassellidae	<i>Dendrolaelaps</i> sp.nov.*		Non-invasive
Scutacaridae	<i>Disparipes antarcticus</i> Richters		Non-invasive
Pygmephoridae	<i>Neopygmephorus</i> sp.		Non-invasive
Glycyphagidae	<i>Glycyphagus domesticus</i> (de Geer)	Storage Mite, Furniture Mite or Food Mite	Non-invasive
Miturgidae	<i>Cheiracanthium furculatum</i> Karsch	Sac Spider	Non-invasive
Linyphiidae	<i>Prinerigone vagans</i> (Audouin)		Invasive
Hypogastruridae	<i>Ceratophysella denticulata</i> (Bagnall)*	Mushroom Springtail	Invasive
Isotomidae	<i>Isotomurus maculatus</i> Müller		Invasive
	<i>Parisotoma notabilis</i> (Schäffer)		Invasive
Tomoceridae	<i>Pogonognathellus flavescens</i> (Tullberg)		Invasive
Neelidae	<i>Megalothorax minimus</i> Willem		Invasive
Aphididae	<i>Macrosiphum euphorbiae</i> (Thomas, C.)		Invasive
	<i>Myzus ascalonicus</i> Doncaster		Invasive
	<i>Rhopalosiphum padi</i> (L.)		Invasive
Thripidae	<i>Apterotherips apteris</i> (Daniel)		Invasive
Noctuidae	<i>Agrotis ipsilon</i> Hufnagel		Invasive
	<i>Agrotis segetum</i> Schiffermüller		Invasive
Nymphalidae	<i>Vanessa cardui</i> (L.)		Invasive
Plutellidae	<i>Plutella xylostella</i> (L.)		Invasive
Calliphoridae	<i>Calliphora vicina</i> Robineau-Desvoidy		Invasive
Chironomidae	<i>Limnophyes minimus</i> (Meigen)*		Invasive
Drosophilidae	<i>Scaptomyza oxyphallus</i> Tsacas		Invasive
Faniidae	<i>Fannia canicularis</i> (L.)*		Invasive
Psychodidae	<i>Psychoda parthenogenetica</i> Tonnoir*		Invasive
Braconidae	<i>Aphidius matricariae</i> Haliday		Invasive
Limacidae	<i>Deroceras panormitanum</i> (Lessona & Pollonera)	Longneck Fieldslug	Invasive
Vertebrates			
Muridae	<i>Mus musculus domesticus</i> Schwarz & Schwarz	House Mouse	Invasive

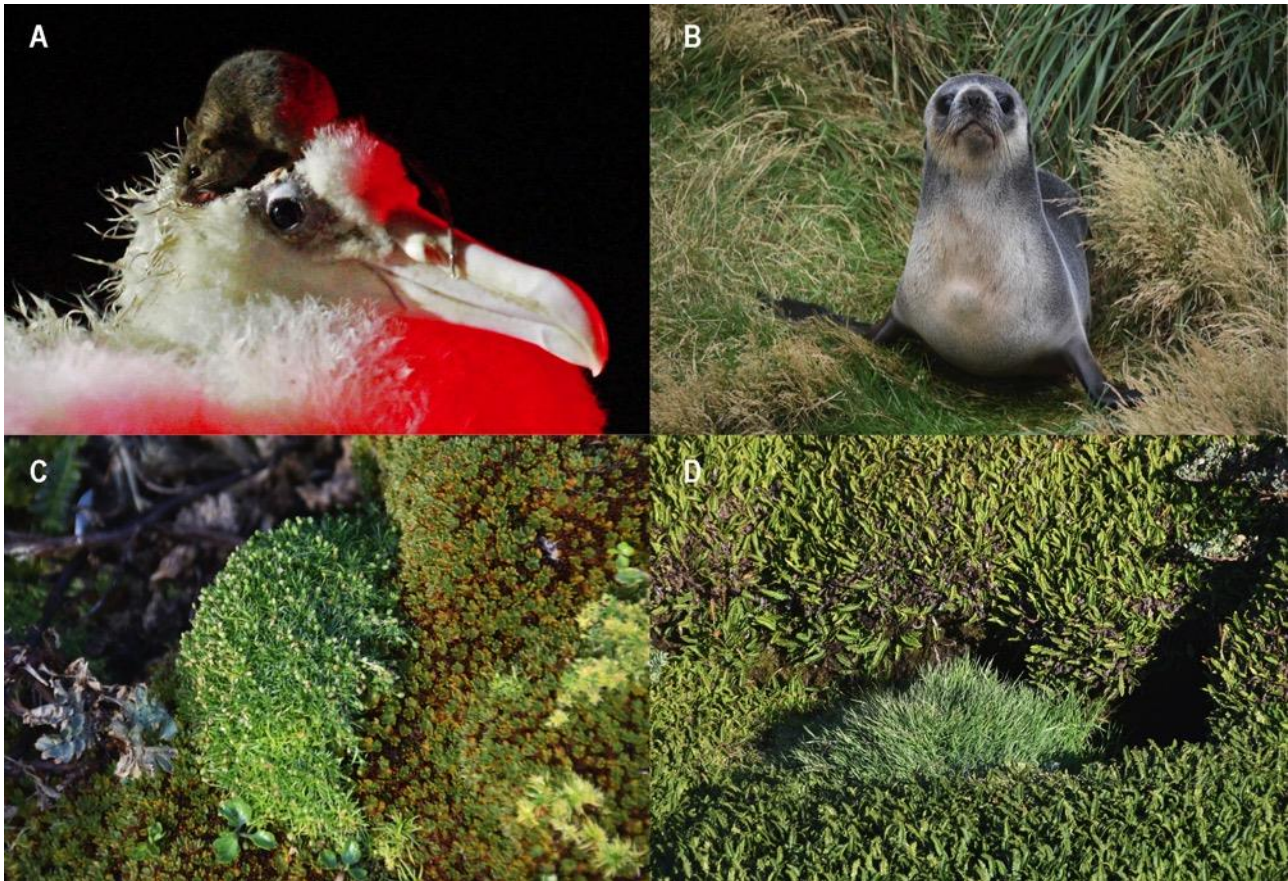


Figure 34. A few of the alien species on Marion Island: A) House Mouse predate on a Wandering Albatross chick, B) invasive *A. stolonifera* forms dense patches between native vegetation in the disturbance of the biotic zone, C) the fastest spreading invasive plant *S. procumbens* growing over native *A. selago* cushion plants, and D) *P. annua* growing in front of a bird burrow. Photos: Stefan and Janine Schoombie (A), Stephni van der Merwe (B-D).

Impacts of specific taxa

Vertebrates

The only established invasive vertebrate species is the House Mouse (Table 14) (Greve et al. 2017). Mice were accidentally introduced to Marion Island, not Prince Edward Islands by sealers in the 1800s (Cooper 2008). Left without sufficient control mechanisms, mice have become the dominant invasive species and threat to biodiversity at the PEIs (Smith et al. 2002, Greve et al. 2017, McClelland et al. 2018). The mouse population has increased by 430% in 30 years due to several interactive effects, including the lack of natural control, the spread of alien plants and invertebrates, and climate amelioration (McClelland et al. 2018).

Mice have impacted all trophic levels on the islands. They deplete the seed stock of some plant species (Chown and Smith 1993) and cause dramatic population declines of macroinvertebrates, as invertebrates constitute the largest proportion of their diet (Smith et al. 2002). Invertebrates are an integral component to decomposition and nutrient cycling on the islands (Smith et al. 2002). Therefore, increased invertebrate predation, which has resulted in an estimated 85% decrease in invertebrate biomass (McClelland et al. 2018), has decreased litter decomposition and impacted ecosystem functioning (Smith et al. 2002). Furthermore, excessive predation on invertebrates has indirectly led to the population decline of the endemic insect-feeding Lesser Sheathbill (Huyser et al. 2000). More recently, seabirds, of which nearly 2.5 million pairs are estimated to breed at the PEIs (Taylor and Peacock 2018), have come under threat from the House Mouse. Mouse predation on petrel and albatross chicks has recently increased, with an estimated 9% mortality (out of the number of birds attacked) in surface-nesting birds, and up to 100 % mortality in burrowing birds (Dilley

et al. 2015, 2017, 2018). Since 2015, ~5 % of summer albatross fledglings have been killed each year (Preston *et al.* 2019). Seabirds at Marion Island already face numerous challenges at sea, including accidental bycatch by commercial fishing vessels. However, the predation of juvenile birds by mice is the largest threat at their breeding grounds and poses a major conservation challenge (Wanless *et al.* 2007, Dilley *et al.* 2018, Preston *et al.* 2019).

The impacts of the House Mouse on native plant species are equally concerning. While depleting seed stocks have been a concern for at least seven plant species' reproductive output (Smith *et al.* 2002), the mice's burrowing activity is causing dieback, and, in some cases, mortality of the keystone species *Azorella selago* (Phiri *et al.* 2009). *Azorella selago* is a cushion plant that creates a favourable microclimate for many of the island's invertebrate and plant species (Hugo *et al.* 2004). Its dieback may thus have many indirect consequences (Figure 35). Mouse burrows and running paths also cause localised changes in plant species composition (Figure 35C) but this is unlikely to have large-scale impacts on plant populations.

While cats were brought to the island in an attempt to control the mice in 1949, they were eradicated by 1991 due to their devastating impact on the seabirds (see Box 3)(Bester *et al.* 2002). Now, South Africa has committed to eradicating the House Mouse in 2021 through a collaborative effort led by the Department of Environment, Forestry and Fisheries, BirdLife South Africa and the Fitzpatrick Institute of African Ornithology (Preston *et al.* 2019). When completed, this will be the largest island-wide eradication of mice in the world using the most ethical methods available that will pose the least threat to the biodiversity of the islands (www.mousefreemarion.org.za).

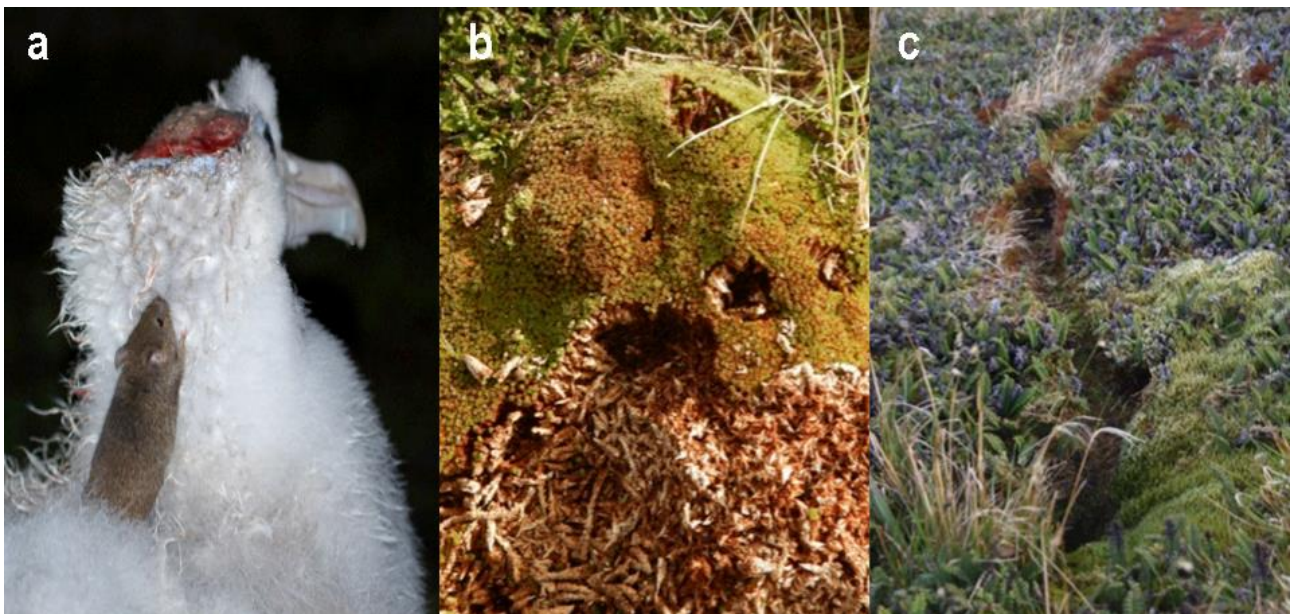


Figure 35. The impacts of mice on biodiversity at Marion Island are widespread, and include (a) 'scalping' of seabird chicks and (b) degradation of vegetation. Paths created by mice (c) lead to changes in plant species composition. Photos: Stefan and Janine Schoombie (a), Stephni van der Merwe (b, c).

Plants

The vascular plant species that have successfully established at the PEIs originate from weedy plant families and many are from similarly cold Northern hemisphere environments (Shaw 2013, Greve *et al.* 2017). Therefore, the alien plant species that are able to establish are inherently adapted to cope with one of the major limiting factors on the islands: temperature (Greve *et al.* 2017). Although early introductions may have occurred when sealers visited the island, most introductions are thought to have occurred during the

construction of the meteorological station on Marion Island in the mid 20th century, and with imports of fodder for livestock that occurred thereafter (Gremmen and Smith 1999, Greve et al. 2019). *Sagina procumbens* (Figure 36) is of particular concern, as it has had the fastest rate of spread ($1.84 \text{ km}^2 \text{ year}^{-1}$ on MI and $2.36 \text{ km}^2 \text{ year}^{-1}$ on PEI) due to its wide ecological tolerance and ability to reproduce vegetatively and by seed (Ryan, Smith, et al. 2003, le Roux et al. 2013). More recent findings suggest that *S. procumbens* facilitates the spread of invasive Collembola species over native Collembola (Twala et al. In Prep), highlighting the interactive effect of invasive species. Furthermore, the invasive grass *Agrostis stolonifera* has altered the composition of invertebrate communities and the structure and seasonality of plant communities (Gremmen et al. 1998). Little else is known about the impacts of invasive plant species at the PEIs.

Table 15. The six most widespread alien invasive vascular plant species at the Prince Edward Islands including year of discovery, area of occupancy estimated in 2013 and rate of spread. Extracted from le Roux et al. (2013) Table 1.

Species	Year of discovery	Area of occupancy (km ²)	Rate of spread (km ² year ⁻¹)*
Marion Island			
<i>Agrostis stolonifera</i>	1965	23.6	0.56
<i>Cerastium fontanum</i>	1973	91.3	0.68
<i>Poa annua</i>	1948	86.6	1.48
<i>Poa pratensis</i>	1965	12.4	0.29
<i>Sagina procumbens</i>	1965	76	1.84
<i>Stellaria media</i>	1973	18.3	0.13
Prince Edward Island			
<i>Cerastium fontanum</i>	1987	4.1	0.19
<i>Poa annua</i>	1966	9.4	0.22
<i>Sagina procumbens</i>	1997	21.8	2.36

* These estimates were calculated for the time period 1966 to 2007.



Figure 36 The rapidly spreading *Sagina procumbens* growing (a) in a native *Blechnum penna-marina* patch and (b) in amongst native bryophytes (bottom left and right). The invasive slug *Deroceras panormitanum* (c) grazes on the native Kerguelen Cabbage and (d) the presumably invasive fungus *Botryotinia fuckeliana* attacks its leaves. Photos: Stephni van der Merwe (a, d, e), Otto Whitehead (b).

Invertebrates

Twenty-eight invertebrate species are known from the PEIs, with Lepidoptera species constituting the most (Table 14)(Greve *et al.* 2019). Most invertebrates were first transported to the islands in fresh produce, packing containers or building material (Hänel *et al.* 1998, Slabber and Chown 2002). Invertebrates are generally inconspicuous and their impacts difficult to measure, thus their influence on native species are often overlooked or poorly represented (Houghton *et al.* 2019). Indeed many invertebrates, such as tardigrades, earthworms and nematodes are insufficiently investigated at the PEIs (Greve *et al.* 2019) and their abundance, richness and impact may thus be underestimated. Of the invertebrates that have been studied, the invasive midge *Limnophyes minimus* has been shown to have both direct and indirect impacts on the ecosystems (Hänel and Chown 1998). The larvae of *L. minimus* are capable of consuming an order of magnitude more litter than native species, significantly altering nutrient cycling in areas where they are most abundant (Hänel and Chown 1998). However, they may have a positive influence by fulfilling certain functions of native decomposers that are the preferred prey of mice (Hänel and Chown 1998). Invasive species also interact with one another. For example, the invasive parasitoid wasp *Asphidius matriciae* parasitizes on an invasive aphid *Rhopalosiphum padi*, thereby controlling aphid populations (Lee and Chown 2016). Understanding these complex interactions is necessary for proper control measures of invasive species. This highlights the importance of understanding the potentially compounding impacts of invasive species.

Other

Little is known about potential invasive non-vascular plants and microbes at the PEIs. *Botryotinia fuckeliana* is the only presumably invasive fungus that has been detected on Marion Island (Kloppers and Smith 1998).

It attacks the leaves of the native Kerguelen Cabbage (*Pringlea antiscorbutica*), causing damage to the leaves (Figure 36 D) (Kloppers and Smith 1998). Although little else is known about the invasive ecology of microbes in the sub-Antarctic, they are easily transported and likely have a fairly high probability of being introduced to its many islands (Mallon et al. 2015).

Despite marine species being able to disperse across long distances, there are no recorded incidences of alien marine species establishing within the sub-Antarctic region, including at the PEIs (Greve *et al.* 2019). However, introductions of marine invasive species may occur with increased vessel traffic and advection of marine debris (McCarthy *et al.* 2019). Alien and potentially invasive species have been observed within hull fouling assemblages on the Antarctic supply vessel, the SA Agulhas I, which makes annual trips to the PEIs (Lee and Chown 2007). The commercial fishery for Patagonian Toothfish may also be a potential vector for transport of alien species, and, despite obligatory compliance of licenced fisheries with conservation measures concerning the prevention of alien invasions set out by CCAMLR, illegal fishing vessels are under no such obligations. Marine debris such as drifting plastics from upstream of the islands may also host fouling assemblages (Barnes and Milner 2005). These assemblages may carry known alien invaders such as the Mediterranean Mussel (*Mytilus galloprovincialis*) which can survive Antarctic temperatures (Lee and Chown 2007).

Responses and monitoring

The status of the PEIs as a Special Nature Reserve means that measures are in place to reduce the potential for further invasions. Eradication of invasive species is a time-consuming and costly endeavour, and thus preventing introduction is the best method to avoid further biological invasions. Biosecurity measures have been in place since the 1990s and have been effective in reducing new introductions (DEA 2010). For example, the annual boot washing ceremony, where footwear is inspected and thoroughly cleaned before arriving at the PEIs, has been implemented to reduce the spread of propagules to the islands via clothing (DEA 2010, Greve *et al.* 2017). Some monitoring of alien species at the PEIs is taking place, as is set out in the DEA management plan for the islands (DEA 2012). Range-restricted alien plant species are actively controlled using pesticides, which has led to the successful eradication of some species (DEA 2012). Nine alien plant species have been effectively controlled since 2012 and ongoing monitoring is being conducted to inform appropriate control measures (DEA 2012). However, for other taxonomic groups, such as invertebrates, eradication of alien plant species is challenging. Other approaches, such as biocontrol and prevention of further introductions should be investigated. The severe impact of the invasive mice has led to plans to have the species eradicated from Marion Island by 2021 (Parkes 2016, Preston *et al.* 2019). The planned eradication will be conducted via an aerial broadcast of rodent poison, an approach that has been successfully implemented on other islands (Parkes 2016, Preston *et al.* 2019). However, other invasive species may have similar, far reaching impacts on the indigenous biota and thus pose a major threat to the island's biodiversity, especially under accelerated climate change (Greve *et al.* 2017, McClelland *et al.* 2018). Plans to control or eradicate other invasive species are more complex, as their impact is often not well known or eradication is not practical.

The South African government and many South African research institutions have long-term commitments to understanding the natural systems on and around the PEIs and will continue their determined efforts to protect and conserve this unique region. In line with this commitment, the South African National Antarctic Programme (SANAP) was created to promote South African research in the sub-Antarctic. Programmes such as SANAP and the more recent Marine Antarctic Research Strategy (MARS), a multi-disciplinary group, help

to ensure that South Africa remains a globally competitive leader in understanding and conserving the region (Ansorge *et al.* 2017).

Box 3: Successful management and eradications of alien species on Marion Island

There have been several success stories for the management of alien species on Marion Island, especially when early detection and intervention occurred. At Marion Island, six alien plant species have been eradicated (Greve *et al.* 2017) and seven are being controlled (DEA 2013). However, the eradication of Feral Cats (*Felis catus*) was the most impressive, and showcases the successful collaboration between governmental departments and research institutions. Cats were taken to Marion Island in 1949 to help control the mouse populations at the research station. Initially they appeared to reduce the mouse population, but the cats soon started targeting seabirds. It is estimated that cats killed nearly 450 000 burrowing birds per year, reducing breeding success of some species to 0% and leading to the localised extinction of the Common Diving Petrel (*Pelecanoides urinatrix*) (Bester *et al.* 2002). Due to their substantial impact, a seven phase eradication programme was initiated in 1974, which included hunting and biological control using a feline virus. By 1991, the last cat had been killed, resulting in the largest and only successful eradication of its kind (Bester *et al.* 2002). Seabird populations have improved since, however, recent increases in mice remains a substantial threat. The planned mouse eradication will support the recovery of seabird populations.



Cats were introduced to Marion Island in 1949. After going feral and preying on seabirds, an eradication programme was launched and the last cat was removed in 1991. Photos: Antarctic Legacy Project, Andre Botha.

Interactions with other pressures

There is a web of interactions associated with invasive species, climate change and their compounding impact on native biota. Climate change is predicted to benefit many invasive species in the sub-Antarctic (Duffy *et al.* 2017). Indeed, range expansion has already been observed in invasive plants, invertebrates and vertebrates (le Roux *et al.* 2013, McClelland *et al.* 2018). The abundance of alien invertebrate species has been shown to be higher under the predicted warmer and drier conditions of future sub-Antarctic climates (McGeoch *et al.* 2006). Increased climate suitability is also predicted to increase successful alien species introductions and benefit invasive species above native species into the future (Duffy *et al.* 2017, Mathakutha *et al.* 2019). Furthermore, the likelihood of marine invasive species introductions in the Southern Ocean may increase, as a result of the weakening of geographic and climatic barriers (Aronson *et al.* 2007, Fraser *et al.* 2013). On the other hand, alien invasive species also threaten the natural resilience of ecosystems to climate change impacts. These species alter the ecological structure and function of the ecosystems, thereby reducing the ability to cope with change. Biologically intact and biodiverse communities are more resilient to

the impacts of climate change. Therefore, the alien invasive species at the PEIs are not only a direct threat to the native biota, but also to the resilience of the natural ecosystems to climate change.

5. THREATS IN THE SUB-ANTARCTIC II – CLIMATE CHANGE

Whitehead, T.O., van der Merwe, S. and Greve, M. 2019. '5: Threats in the sub-Antarctic II - Climate Change', in *National Biodiversity Assessment 2018 Technical Report Volume 6: sub-Antarctic Territory*. Whitehead, T.O., Von der Meden, C., Skowno, A.L., Sink, K.L., van der Merwe, S., Adams, R. and Holness, S. (eds.). South African National Biodiversity Institute, Pretoria.



The interior of Marion Island mid-winter. Photo: Otto Whitehead.

Introduction

Since the 19th century industrial revolution, the concentration of atmospheric carbon dioxide has increased by 40%, leading to rapid warming of the Earth's atmosphere and oceans (IPCC 2014). The oceans are important regulators of the Earth's climate, with the Southern Ocean playing the largest role, being responsible for ~40% of the ocean's total annual uptake of atmospheric carbon (Watson *et al.* 2014, Le Quéré *et al.* 2016) and ~10% of the total annual uptake of anthropogenic carbon emissions (Khaliwala *et al.* 2009). Changes to Southern Ocean ecosystems thus have consequences for the whole planet. In the last 60 years, the Southern Ocean has warmed by more than 1 °C, impacting the seasonality and extent of sea ice around Antarctica (Constable *et al.* 2014). The Southern Annular Mode (SAM) – a low frequency index of atmospheric variability and the position of the westerly wind belt – has become more positive, which is evident in the southward shifts of storm tracks and major frontal systems (Gille 2002, Ansorge *et al.* 2009a, Sokolov and Rintoul 2009). The core belt of westerly winds that drive the easterly-flowing Antarctic Circumpolar Current (ACC) has strengthened and moved south (Fyfe *et al.* 2007), changing circulation (Armour *et al.* 2016), upwelling mechanisms and nutrient replenishment (Constable *et al.* 2014, Treasure *et al.* 2018). This has influenced primary productivity and altered the abundance and distribution of key mesopelagic organisms (e.g. krill, squid, lanternfish) (Deppeler and Davidson 2017, Freer *et al.* 2019). Many marine mammals and seabirds have experienced population declines attributed to food limitations, particularly during the breeding season (Barbraud and Weimerskirch 2001, Weimerskirch *et al.* 2003). This chapter focuses on climate-driven changes at the Prince Edward Islands (PEIs) and in the surrounding Southwest Indian Ocean sector of the Southern Ocean.

Variability in climatic and ocean processes

The climate at the PEIs is strongly influenced by the ocean, as evident from the correlation between sea and air temperatures (Smith and Steenkamp 1990). The climate is characterised by cold but stable temperatures, high precipitation and humidity, strong winds and near complete cloud cover on most days – typical of sub-Antarctic islands (Le Roux and McGeoch 2008a). Being located in the westerly wind belt, winds and currents predominantly originate from the west (Rouault *et al.* 2005). Transient frontal systems drive short-term variability in weather, including rapid changes in air temperature, wind direction and precipitation (Le Roux and McGeoch 2008a). Positions of major oceanic fronts associated with the ACC – the Sub-Antarctic (SAF) and Antarctic Polar Fronts (APF) – fluctuate throughout the year, driving variability in local and distant oceanic processes (Ansorge *et al.* 2009a, Asdar 2018).

When the SAF is farther north, currents near the islands are slower and cooler waters persist, and when it is closer to the islands, the currents strengthen and warmer waters persist (Hunt *et al.* 2001a, Treasure *et al.* 2018, Lamont *et al.* 2019). Interactions of the ACC with major bathymetrical features such as the Southwest Indian Ridge (SWIR) disrupt flow, inject nutrients into surface waters via upwelling and enhance primary productivity. The SWIR generates an eddy 'conveyor belt' that sustains and transports elevated aggregations of zooplankton and micronekton towards the PEIs, providing millions of marine mammals and seabirds with food (Durgadoo *et al.* 2010). Local upwelling at the PEIs and nutrient-laden freshwater run-off enriches local and downstream food webs – a process known as the *island mass effect* (Allan *et al.* 2013). This stimulates productivity and sequestration of carbon from surface waters to the deep ocean, providing a valuable contribution to the biological carbon pump in the Southern Ocean (Watson *et al.* 2014).

Changes in the sub-Antarctic

Pre-industrial

Geological evidence estimates that the PEIs are ~0.5 million years old and have experienced several glacial maxima corresponding to marine oxygen isotope stages 2, 4, 6, 8, and 12 (McDougall *et al.* 2001). The Last Glacial Maximum occurred ~ 21,000 years ago, a time when the Antarctic ice sheet was at its full extent, Marion Island was almost entirely covered by ice, and major fronts were 2-10° farther north (Hall *et al.* 2011, Watson *et al.* 2014). Evidence from pollen records at Marion Island shows the appearance of Fellfield vegetation once the ice receded during the early Holocene (Scott 1985). Fellfield communities were succeeded by peats and mire vegetation but changes were likely driven by drainage patterns and moisture availability rather than temperature amelioration (Scott 1985, Yeloff *et al.* 2007). Since the Last Glacial Maximum, air and sea temperatures have warmed, surface waters have decreased in salt content, sea levels have risen and permanent ice cover has disappeared (Figure 37) (Sumner *et al.* 2004, Swart *et al.* 2018).



Figure 37. Historical and recent images of Marion Island's interior (Meiklejohn 2011).

Post-industrial

Since monitoring began in the 1950s, mean annual air and sea temperatures at the PEIs have increased by 1.2 and 1.4 °C, respectively (Le Roux and McGeoch 2008a) – more than twice the mean global rate (Ansorge *et al.* 2017). The mean track of passing storms has shifted south of the islands and these have become less frequent (10% decrease between 1970 and 1997; (Fyfe 2003). This has allowed more warm and moist air masses to be advected from the north and altered wind patterns; cool westerly winds have weakened and become less frequent, and warmer northerly winds have strengthened and become more common (since 1980; (Rouault *et al.* 2005). Such dramatic changes to weather patterns have resulted in less precipitation (Le Roux and McGeoch 2008a). The average position of the SAF appears to have shifted southwards (Hunt *et al.* 2001b, Ansorge *et al.* 2009b), resulting in more frequent intrusions of warmer, more saline, faster-flowing waters to the islands (Treasure *et al.* 2018, Lamont *et al.* 2019). Such profound physical changes have impacted the ecology of terrestrial and marine ecosystems.

Terrestrial

Major changes in the terrestrial climate of the PEIs include warmer air temperatures (Le Roux and McGeoch 2008a), altered wind patterns (Rouault *et al.* 2005) and less rainfall (Le Roux and McGeoch 2008a), which have impacted landscape processes and plant and invertebrate communities.

Warmer air temperatures have shifted isotherms to higher altitudes, resulting in the disappearance of a permanent snow line and the reduction of Marion Island's ice plateau (Sumner *et al.* 2004; Boelhouwers *et al.* 2008)(Figure 37). Plant communities and nutrient cycling have been impacted (Smith 2002, Le Roux and McGeoch 2008b); of fourteen of the most common native plant species, six (43%), all habitat generalists, have expanded upslope (Le Roux and McGeoch 2008b, le Roux *et al.* 2013). This has resulted in novel plant community composition at higher altitudes (Le Roux and McGeoch 2008b). Nutrient cycling at the islands is largely performed by soil macroinvertebrates, which are temperature-limited (Smith 2002). Warming may increase rates of litter consumption and enhance nutrient release (Smith 2002), although this may be limited at Marion Island by the dramatic reduction of macroinvertebrates due to predation by invasive mice (Smith *et al.* 2002, McClelland *et al.* 2018). Warmer temperatures may have contributed to observed declines in the endemic Flightless Moth (*Pringleophaga marioni*) and several weevil species that have low upper thermal tolerances (Jaco Klok and Chown 1997, Van der Merwe *et al.* 1997). Current microhabitat temperatures are close to the upper thermal tolerance of native invertebrates and may be exceeded in the near future as temperatures increase, resulting in reduced invertebrate abundances (Chown 2001). Some invasive invertebrates have higher thermal tolerances than native species and will likely benefit from continued warming at the expense of native species (Slabber *et al.* 2007). Similarly, warmer conditions may exacerbate the spread of invasive plants and compound their negative effect on native species (McClelland *et al.* 2018, Greve *et al.* 2019). Direct impacts of warming on the island's marine mammals and seabirds are not well studied; however, increasing temperatures and sunshine, particularly during late summer, may affect surface-nesting seabirds through heat stress (Oswald and Arnold 2012).

The reduction in strength and frequency of westerly winds has reduced the transfer of airborne salt to some inland habitats, resulting in range contractions of halophilous (salt-loving) species such as *Cotula plumosa* and *Crassula moschata* (Le Roux and McGeoch 2008b). Contrastingly, the strengthening of easterly winds has likely increased the transfer of airborne salt to inland habitats on the east coast. The impacts of fewer days without wind are unknown, but given the strong influence of wind exposure on the distribution, abundance, growth and structure of plant and invertebrate communities (Smith and Steenkamp 1990, Le Roux and McGeoch 2008a), any changes to wind patterns will likely alter the fine-scale and altitudinal distribution of plant and invertebrate communities (Le Roux and McGeoch 2008b, 2008a).

There are more days without frost. Native plant species invest more strongly in conservative traits to deal with the harsh sub-Antarctic climate than invasive plants (Mathakutha *et al.* 2019). Fewer frost events may benefit invasive species that are less frost tolerant and give them a competitive advantage over native species. Up-slope shifts of invasive species is already evident at Marion Island (le Roux *et al.* 2013).

Mean annual precipitation has declined by 34% since the 1960s (2727 mm vs. 1778 mm between 2007-2016) and **periods without rainfall have become longer** (Le Roux and McGeoch 2008a, Hedding and Greve 2018). Although the impacts of decreased rainfall on terrestrial systems at the PEIs are not well understood, anecdotal evidence suggests that less rainfall has resulted in diebacks of bryophytes and vascular plants, and the drying out of peats and mire lakes (Hedding and Greve 2018)(Figure 38). Increased duration between rainfall events reduces soil moisture in ecosystems with well-drained, dry soils or where strong winds increase evaporation, such as the high altitude Fellfield or Polar Desert communities (Le Roux and McGeoch 2008a). Here, early stem senescence has been observed in the cushion plant *Azorella selago* (Le

Roux *et al.* 2005), with similar responses at Kerguelen Island and in sister taxon *A. macquariensis* at Macquarie Island (Bergstrom *et al.* 2015). *Azorella selago* is a pioneer keystone species that is sensitive to fine-scale changes, and its dieback has likely had knock-on effects for invertebrates and other plant species that depend on it (Phiri *et al.* 2009). More days without rainfall have also resulted in population increases of invasive house mice by ameliorating the impact of wet nights that reduce thermal insulation and increase energetic costs (McClelland *et al.* 2018). Higher mouse populations have severely impacted plant, invertebrate and bird populations (Huyser *et al.* 2000, Dilley *et al.* 2018, McClelland *et al.* 2018, van der Merwe *et al.* 2019). Reduced freshwater input into the island's streams may have had cross-realm impacts by reducing the flow of guano and nutrient-laden freshwater into the sea (Hedding 2006, Stowe *et al.* 2018), potentially impacting nearshore algal communities and detritivores (Allan *et al.* 2013, Ansorge *et al.* 2017).



Figure 38. The first drying out of peats and mire lakes were recently recorded, and included diebacks of ferns, bryophytes and vascular plants, shown in this aerial photograph (Hedding and Greve 2018). Photo: David Hedding.

Box 4: The curious case of the Gentoo Penguin and the benthic shrimp

Limited foraging ranges and a year-round presence at the Prince Edward Islands (PEIs) make Gentoo Penguins (*Pygoscelis papua*) excellent sentinels of change. This northern subspecies *P. papua papua* is at the northern limit of its range, making it particularly vulnerable to recent warming. Since the 1980s, their population at the PEIs has declined by 50% (Crawford *et al.* 2014). In the 1980s, Gentoo penguins fed mostly on benthic shrimp (*Nauticaris marionis*), but recent studies have revealed a major dietary shift to pelagic prey such as *Euphausia vallentini* and juvenile nototheniid fish (Carpenter-Kling *et al.* 2019). Similar dietary shifts and population declines have been observed for Macaroni and Rockhopper Penguins (Crawford *et al.* 2003a, 2003b, Crawford *et al.* 2009).



Populations of Gentoo Penguins have declined by 50% since the 1980s.
Photo: Otto Whitehead.

Intrusions of warmer water associated with the Sub-Antarctic Front have become more common at the PEIs, limiting the formation of local phytoplankton blooms and changing the trophic structure and composition of benthic communities (Von der Meden *et al.* 2017). It may be assumed that the decline of *N. marionis* in the diet of inshore predators may have resulted from reduced availability of *N. marionis*, but recent surveys (mostly at depths > 50 m) have not detected any changes in *N. marionis* densities since the 1980s (Haley *et al.* 2017). Shallow (< 30 m) parts of the shelf (where predators often feed) are, however, undersampled. In these waters, *N. marionis* relies on red algae as their main habitat (Branch *et al.* 1993) but it is not known how these shallow habitats have responded to changes in sea temperature and flow. In deeper waters (> 50 m), densities of habitat-forming bryozoans and polychaetes have increased, which has benefitted benthic fishes such as *Lepidonotothen squamifrons* and *L. larseni* (von der Meden *et al.* 2017). Contrary to the decline of the northern subspecies, the southern Gentoo Penguin (*P. papua ellsworthii*) is thriving in many parts of Antarctica as more ice-free habitat becomes available (Carlini *et al.* 2009).

Marine

During the past 60 years, the average position of the SAF has shifted ~1° south (Hunt *et al.* 2001a, Gille 2002, Ansorge *et al.* 2009a, Sokolov and Rintoul 2009), leading to increases in sea temperature and the strengthening of currents near the islands.

Increased intrusions of warmer waters to the islands have altered the species composition of allochthonous (derived from elsewhere) epipelagic communities near the islands, with Antarctic species decreasing and sub-Antarctic and sub-Tropical species becoming more common (Ansorge *et al.* 2009a). This may impact seals and seabirds; as sub-Tropical zooplankton have lower lipid compositions are less energy dense than Antarctic species (Attwood *et al.* 1991).

Faster currents at the islands have increased the frequency of flow-through conditions, preventing the stratification of water between the islands and **reducing locally-derived primary production** (Pakhomov and Chown 2003). Enhanced food delivery associated with faster currents has benefitted benthic filter feeders

such as the bryozoan *Cellaria malvinensis* and tube-building polychaete *Lanice marionensis*, which have increased in abundance since the '80s (Von der Meden *et al.* 2017). This has indirectly benefitted nototheniid fish such as *Lepidonotothen squamifrons* and *L. larseni* that rely on biogenic structures for refuge (Von der Meden *et al.* 2017). Reduced local productivity has impacted the trophic ecology of benthic organisms such as the benthic shrimp *Nauticaris marionis*, which has shifted its diet to more allochthonous sources (Pakhomov *et al.* 2004, Allan *et al.* 2013). Over the same period, *N. marionis* has become scarcer in the diet of inshore-foraging seabirds, such as the Crozet Shag and Gentoo, Macaroni and Rockhopper Penguins, which have shifted to feeding on more allochthonous prey such as krill *Euphausia vallentini* and *Thysanoessa vicina* (Crawford *et al.* 2003a, Crawford *et al.* 2014, Carpenter-Kling *et al.* 2019). This suggests densities of *N. marionis* may have decreased in shallow waters – potentially contributing to population declines of inshore-foraging seabirds (Crawford *et al.* 2009, 2014); (see Box 4) – but recent evidence indicates that densities of *N. marionis* have remained stable (Haley *et al.* 2017).

Eddy activity at the Southwest Indian Ridge has decreased (Asdar 2018). These eddies advect nutrients, stimulate phytoplankton growth and aggregate high concentrations of zooplankton and micronekton as they move eastwards towards the PEIs, forming a *conveyor belt* of food for upper trophic level (UTL) predators (Ansorge *et al.* 2009a). Recent population declines of inshore predators suggest food limitations (Crawford *et al.* 2009, 2014). By contrast, populations of long-range predators such as albatrosses, petrels and seals are mostly stable or increasing (Allan *et al.* 2013). Several predators rely on mesoscale eddies as foraging areas (Nel *et al.* 2001, Whitehead *et al.* 2016), however, it is unknown how changes in eddy dynamics will impact their ability to find and access prey at remote areas (ranging from Antarctic to South Africa) (Reisinger *et al.* 2018). There is little research into the impacts of ocean acidification on marine ecosystems at the PEIs, but there is growing evidence for its impacts on crustaceans and other calcifying organisms elsewhere in the Southern Ocean (Constable *et al.* 2014).

Future predictions

The long-term warming trend in the Southern Ocean is clear (Swart *et al.* 2018) but it is unknown at what rate change will occur in response to escalating anthropogenic carbon emissions (IPCC 2014). According to IPCC climate models, the best and worst case scenarios predict increases in global atmospheric temperatures ranging from 1.5 to 4 °C by 2100 (IPCC 2014). Concurrent warming of the Southern Ocean, continued poleward migration of major frontal systems and decreased eddy generation are expected to have major consequences for marine and terrestrial ecosystems at the PEIs. A more southerly SAF means intrusions of warmer, saltier water to the PEIs will become more common, increasing the proportions of sub-Antarctic and sub-Tropical species in pelagic communities. More flow-through conditions over the island shelf will limit eddy retention, reducing local productivity and altering benthic food webs. Changes to upstream pelagic food webs will impact local food availability for inshore and medium-range foraging predators, particularly during the constrained breeding season (Whitehead 2017, Carpenter-Kling *et al.* 2019).

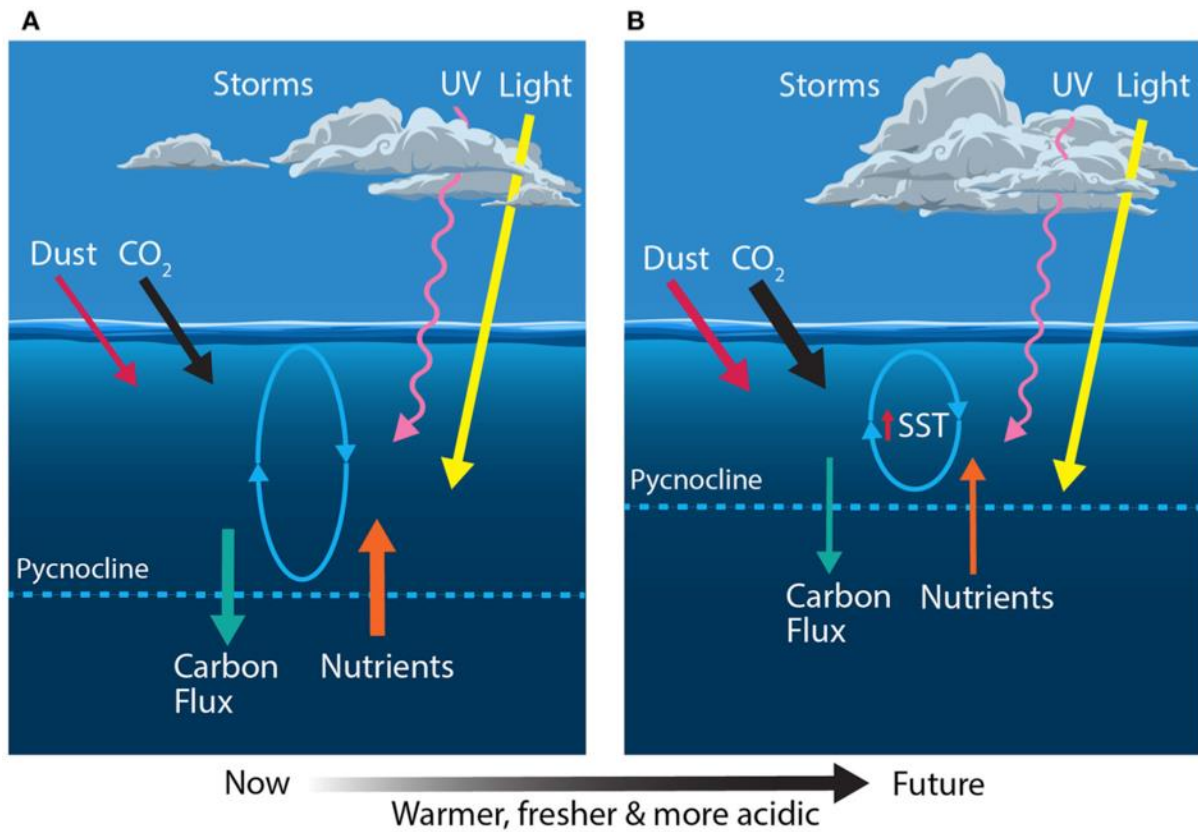


Figure 39. Primary physical constraints on phytoplankton in the Sub-Antarctic Zone (SAZ) (A) before and (B) after climate change. Arrow thickness reflects relative rates of flux (reproduced from Deppeler & Davidson 2017).

The poleward migration of the APF has major implications for top predators (Nel *et al.* 2001, Whitehead *et al.* 2016, Pistorius *et al.* 2017a), particularly King Penguins (*Aptenodytes patagonicus*) that feed on aggregations of lanternfish. By 2100, the APF and its associated lanternfish may be too far south for King Penguins to adequately provision offspring (Freer *et al.* 2019), resulting in colony collapses at the PEIs and elsewhere in the sub-Antarctic (Cristofari *et al.* 2018). Far-ranging predators such as albatrosses may be less impacted by local marine ecosystem changes, but it is unknown how they will be affected by changes to food abundance and predictability at distant foraging areas such as at the Sub-Tropical Convergence and Southwest Indian Ridge (Reisinger *et al.* 2018). Less rainfall, rising air temperatures, changing wind patterns and altered contributions of salt-spray in terrestrial ecosystems will continue to impact the distribution and composition of plant and invertebrate communities (Le Roux and McGeoch 2008a, 2008b). If seal and seabird populations decline in response to marine ecosystem changes, the extent of trampling and manuring at the PEIs will decrease, altering plant communities reliant on these processes. A more temperate climate will exacerbate the spread of existing alien invasive species and compound their negative effect on native species (le Roux *et al.* 2013, Greve *et al.* 2017, McClelland *et al.* 2018). The likelihood of arrival and establishment of new marine and terrestrial invasive species, including pathogens and microbes, is also expected to increase due to the weakening of geographic and climatic barriers (Aronson *et al.* 2007, Duffy *et al.* 2017, McClelland *et al.* 2018). Continued increases in atmospheric CO₂ and increased overturning of CO₂-rich subsurface waters by stronger westerly winds are predicted to acidify surface waters, leading to undersaturation of calcium carbonate and impacting calcareous, shell-forming organisms (Orr *et al.* 2005, Watson *et al.* 2014) such as coccolithophorid phytoplankton and aragonite-forming zooplankton (Bernard 2006, Deppeler and Davidson 2017). Reduced productivity of these lower trophic organisms will impact top predators and decrease the transfer of carbon from surface waters to the deep sea. Such major changes to the Southern Ocean will have

major consequences for pelagic and benthic ecosystems at the PEIs and will impact their role in the global carbon cycle.

Responses and monitoring

The Prince Edward Islands (PEIs) receive full protection under the Antarctic Treaty System and are managed by the South African National Antarctic Program (SANAP) under the Department of Environment, Forestry and Fisheries (DEFF). South Africa is committed to conserving the PEIs through agreements with the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Agreement for the Conservation of Albatrosses and Petrels (ACAP). The islands are managed as a Special Nature Reserve under the NEMA: Protected Areas Act 57 of 2003 and receive the highest level of protection of any South African natural area. The Marine Protected Area (MPA) limits fishing in 5% of the ocean and provides some protection to important foraging areas of killer whales, albatrosses, petrels, seals and penguins (Nel *et al.* 2001, Kirkman *et al.* 2016, Reisinger *et al.* 2018). This legislation is important to enhance the resilience of marine and terrestrial ecosystems to climate change. Further research on the impacts of climate change on marine and terrestrial ecosystems at the PEIs and their role as a carbon sink are underway through a variety of projects.

To better understand the impacts of climate change, researchers need time, thus making long-term monitoring essential. The PEIs are an important sentinel for climate change not only because they are changing so rapidly but also because baseline surveys were conducted many decades ago. Meteorological observations have been performed since 1949, which have provided *in situ* records of weather over the past 70 years (Smith 2002, Mélice *et al.* 2003, Rouault *et al.* 2005). Early geological and botanical surveys, and the use of photography, have revealed changes in geomorphology and plant communities (Meiklejohn 2011, Hedding and Greve 2018). Long-term monitoring of seals and seabirds since the 1980s has revealed population and dietary changes (Crawford *et al.* 2003a, 2003b, Crawford *et al.* 2009, Wege *et al.* 2016, Carpenter-Kling *et al.* 2019). Changes in stable isotope signatures of their critical prey species, *Nauticularis marionis*, of top predators have been conducted, provide further evidence of ecosystem changes in the sub-Antarctic (Pakhomov *et al.* 2004, Allan *et al.* 2013). Furthermore, advances in remote sensing and bio-logging technologies have increased our understanding of oceanographic processes and provided insights into how top predators use and respond to the marine environment and change therein (Kirkman *et al.* 2016, Whitehead *et al.* 2016, Pistorius *et al.* 2017b, Makhado *et al.* 2018, Reisinger *et al.* 2018). Since 2014, permanent buoys have been anchored between the islands, providing year-round *in situ* measurements of local sea temperatures and current speeds (Lamont *et al.* 2019). Investigations by a multitude of institutions continue to unravel the physical processes that drive productivity, responses of top predators to shifting resources, the influence of faster currents and warmer waters on benthic ecosystems, the effect of warmer and drier conditions on plant and invertebrate communities, and the impacts of invasive species with climate amelioration. The rapid rate of change in this sector of the Southern Ocean and the scarceness of *in situ* data make the PEIs a globally important location to monitor and research the impacts of climate change. It is therefore vital that long-term monitoring projects are maintained (Ansorge *et al.* 2017).

Box 5: Climate change and the invasive House Mouse

The compounding effects of climate change on invasive species impacts are of major global concern. The House Mouse (*Mus musculus*) was accidentally introduced to Marion Island in the 1800s where it has become invasive. Since the first mouse population estimates in 1979, the number of mice has increased by 430% and are estimated to number more than 1.7 million individuals (McClelland *et al.* 2018). The severity of their impacts on the island's native plants, invertebrates and seabirds is well documented (see van der Merwe *et al.* 2019 for more details) and has been compounded by recent climate amelioration (Smith 2002, McClelland *et al.* 2018). Mice are strongly temperature-limited and live close to their physiological limits at Marion Island (Smith 2002, Avenant and Smith 2003). They are mostly active at night, but are not well adapted to foraging in wet conditions as thermal insulation is reduced and the energetic costs are high (McClelland *et al.* 2018). More precipitation-free nights (200% increase since the 1960s; McClelland *et al.* 2018) has alleviated many energetic restraints previously faced by the mice, and has allowed them to forage more often, increasing their energy intake for breeding (McClelland *et al.* 2018). Ultimately, recent climate change at Marion Island has led to the explosion of the mouse population and exacerbated their impact on the island's native species. Mice are now the most serious terrestrial threat at Marion Island and their eradication is critical for the future preservation and restoration of its ecosystems (Preston *et al.* 2019) and to maintain ecological resilience in the face of future climate change.



Mice climb onto the heads of juvenile Greyheaded Albatrosses and feed on their blood. To ensure the future survival of these species, it is vital that the House Mouse is eradicated from Marion Island. Photo: Peter Ryan.

Table 16. Summary of observed and predicated impacts of climate change in the sub-Antarctic territory.

	Observed impacts	Predicted impacts
Species	• Gentoo penguin population declined and diet changed due to more southerly SAF (Carpenter-Kling <i>et al.</i> 2019). • Crozet Shags have declined (Crawford <i>et al.</i> 2015). • Weevils more vulnerable (Klok & Chown 1997). • Flightless moth closer to threshold temperatures (van der Merwe <i>et al.</i> 1997). • Macaroni and rockhopper penguins have declined in numbers (Crawford <i>et al.</i> 2009). • Benthic bryozoans and polychaetes have increased in abundance (von der Meden <i>et al.</i> 2017) • Azorella selago increasing stem senescence (le Roux <i>et al.</i> 2005). • Lesser sheathbill abundance has declined (Huyser <i>et al.</i> 2000). • Six native plant species have expanded their altitudinal distributions (le Roux & McGeoch 2008b).	• King penguins may go extinct by 2100 due to distance of APF (Cristofari <i>et al.</i> 2018). • Gentoo penguins expected to decline in northern extent of range. • Benthic invertebrates and calcifying organisms expected to be impacted by increasing ocean acidification. • Macaroni and rockhopper penguins will continue to be restricted to feeding on changing pelagic food webs. • Six weevils and the flightless moth could reach an upper thermal tolerance.
Ecosystem/ Biome	• Air temperature has warmed by 1.2 °C since 1950 (Roualt <i>et al.</i> 2005). • Sea temperature has warmed by 1.4 °C since 1950 (Melice <i>et al.</i> 2003). • Ocean currents near the islands have strengthened (Treasure <i>et al.</i> 2018). • Wind patterns have changed, with NW more common and days without wind are fewer (Rouault <i>et al.</i> 2005). • Rainfall has decreased by 34% since 1970 and days without rainfall are increasing (Hedding & Greve 2018). • Ice plateau and ice caves are disappearing; loss of permanent snow line (Sumner <i>et al.</i> 2004). • Eddies frequency has decreased but intensity has increased (Asdar 2018). • Major frontal systems have shifted south (Ansorge <i>et al.</i> 2009).	• Island mass effect may decline in intensity due to less rainfall and local productivity. • Westerly winds are expected to strengthen south of the islands. • Storm tracks may continue to move south of the islands. • Eddies will decline in frequency and increase in intensity (Asdar 2018). • Rainfall will continue to decline, creating drier conditions. • Air temperatures will increase, expanding altitudinal ranges of isotherms. • Sea temperatures are expected to increase. • Closer SAF will create more flow-through conditions if it continues to move southward.
Ecosystem Services	• Decreased local primary productivity means less input into downstream food webs and reduced carbon sequestration. • Reduced ecosystem resilience.	• Ocean acidification will impact shell-forming organisms and reduce the carbon flux to deep sea.
Invasive species	• House Mouse populations have increased by 430%, amplifying negative effects on native species (McClelland <i>et al.</i> 2018). • Range expansions of invasive plants (le Roux <i>et al.</i> 2013, Mathakutha <i>et al.</i> 2019).	• More mice will survive due to climate amelioration (McClelland <i>et al.</i> 2018). • Abundance of alien invasive invertebrates and plants predicted to increase at the expense of native species, under warmer and drier climate (McGeoch <i>et al.</i> 2006; Mathakutha <i>et al.</i> 2019.) • Increasingly temperate climate will increase the likelihood of invasions by alien species (Smith 2002; Chown <i>et al.</i> 2008; Duffy <i>et al.</i> 2017).

6. KEY FINDINGS, PRIORITY ACTIONS AND KNOWLEDGE GAPS

Sink, K.L., Whitehead, T.O., van der Merwe, S., Adams, R. and Kirkman, S. 2019. '6: Key Findings, Priority Actions and Knowledge Gaps' in *National Biodiversity Assessment 2018 Technical Report Volume 6: sub-Antarctic Territory*. Whitehead, T.O., Von der Meden, C., Skowno, A.L., Sink, K.L., van der Merwe, S., Adams, R. and Holness, S. (eds.). South African National Biodiversity Institute, Pretoria.



A Wandering Albatross chick in the middle of winter. Photo: Otto Whitehead.

Introduction

The NBA is a collaborative effort to synthesise the best available science on South Africa's biodiversity covering ecosystems, species and genes and including their condition, pressures, benefits and existing responses to inform decisions in a range of sectors. This chapter identifies priority actions to address the key findings of the NBA 2018 for the terrestrial and marine realms of South Africa's sub-Antarctic territory. These are related to the National Biodiversity Strategy and Action Plan (NBSAP) and the National Biodiversity Framework (NBF) and linked to priorities through the broader cross-realm analyses from the NBA 2018 (Skowno *et al.* 2019). The limitations to this assessment are also presented in this chapter with a view to determine additional priority actions to address these knowledge gaps. As such, the NBA helps to distil a number of key research priorities that if addressed will improve the knowledge base to assess and manage biodiversity in South Africa.

The NBSAP-NBF-NBA relationship informs priority actions

South Africa has a well-developed suite of policy and legislation for the management, conservation and sustainable use of biodiversity, including two overarching national tools: The National Biodiversity Strategy and Action Plan (NBSAP) and the National Biodiversity Framework (NBF). These documents, developed through thorough stakeholder consultation, set out South Africa's strategic objectives for managing and conserving biodiversity and are the primary reference points for related priority actions. The NBA both informs the development of the NBSAP and NBF, and supports their implementation. Together, the NBSAP, NBF and NBA provide three key, inter-related anchors for the work of the biodiversity sector in South Africa. As our sub-Antarctic territory was not previously assessed, there is limited reference to this in the current NBSAP and NBF, however, this new assessment will support further inclusion of more specific elements of sub-Antarctic biodiversity in the future.

An **NBSAP** is a requirement that all contracting parties to the Convention on Biological Diversity (CBD) are obliged to fulfil. South Africa's first NBSAP was completed in 2005, and the second in 2015, in both cases drawing on the preceding NBA. The NBSAP 2015-2025 sets out an integrated and coherent national strategy for the conservation, management and sustainable use of the country's biodiversity to ensure equitable benefits to the people of the country. It outlines how South Africa will fulfil the objectives of the CBD and contribute to the global sustainable development agenda. It also provides a framework for the integration of biodiversity considerations into national development plans and a wide range of other sectoral strategies, placing wise management and protection of biodiversity at the heart of the sustainable development agenda. The NBSAP identifies six Strategic Objectives, under each of which are key outcomes, activities (designated as high, medium and low priority), and medium to long-term targets, which are described in detail.

The **NBF** is developed as a requirement of the Biodiversity Act, and published by the Minister of Environment, Forestry and Fisheries, with the purpose of coordinating and aligning the efforts of the many organisations and individuals involved in conserving and managing South Africa's biodiversity in support of sustainable development. The first NBF was developed in 2008 and the second in 2017. The NBF is a short to medium-term coordination tool that shows the alignment between the strategic objectives and outcomes identified in the NBSAP and other key national strategies, frameworks and systems that currently guide the work of the biodiversity sector, building on the consultative processes through which all of these other products were developed. This is complemented by an overview of national policy and legislation and international commitments relevant to the biodiversity sector, and a description of national level coordination mechanisms and communities of practice through which sector representatives can coordinate their work and exchange information and experiences. The NBF also identifies a set of interventions or 'acceleration

measures' that can unlock or fast-track implementation of the NBSAP, and indicates the relative roles of the many agencies involved in implementing these activities.⁸

The **NBA relates to the NBSAP and NBF** in two main ways: 1) the NBA informs the *development* of the NBSAP and NBF, by providing a strong scientific foundation on the pressures on biodiversity and how they are impacting on its status, and thus directing the key focus for society's interventions; 2) the NBA supports the *implementation* of the NBSAP and NBF, by providing science-based evidence that helps to ensure effective action in the right places. In brief, the NBA provides the science that informs the strategic objectives and priority actions of the NBSAP and NBF. Together, the NBSAP, NBF and NBA provide three key anchors for the work of the biodiversity sector (Figure 40).

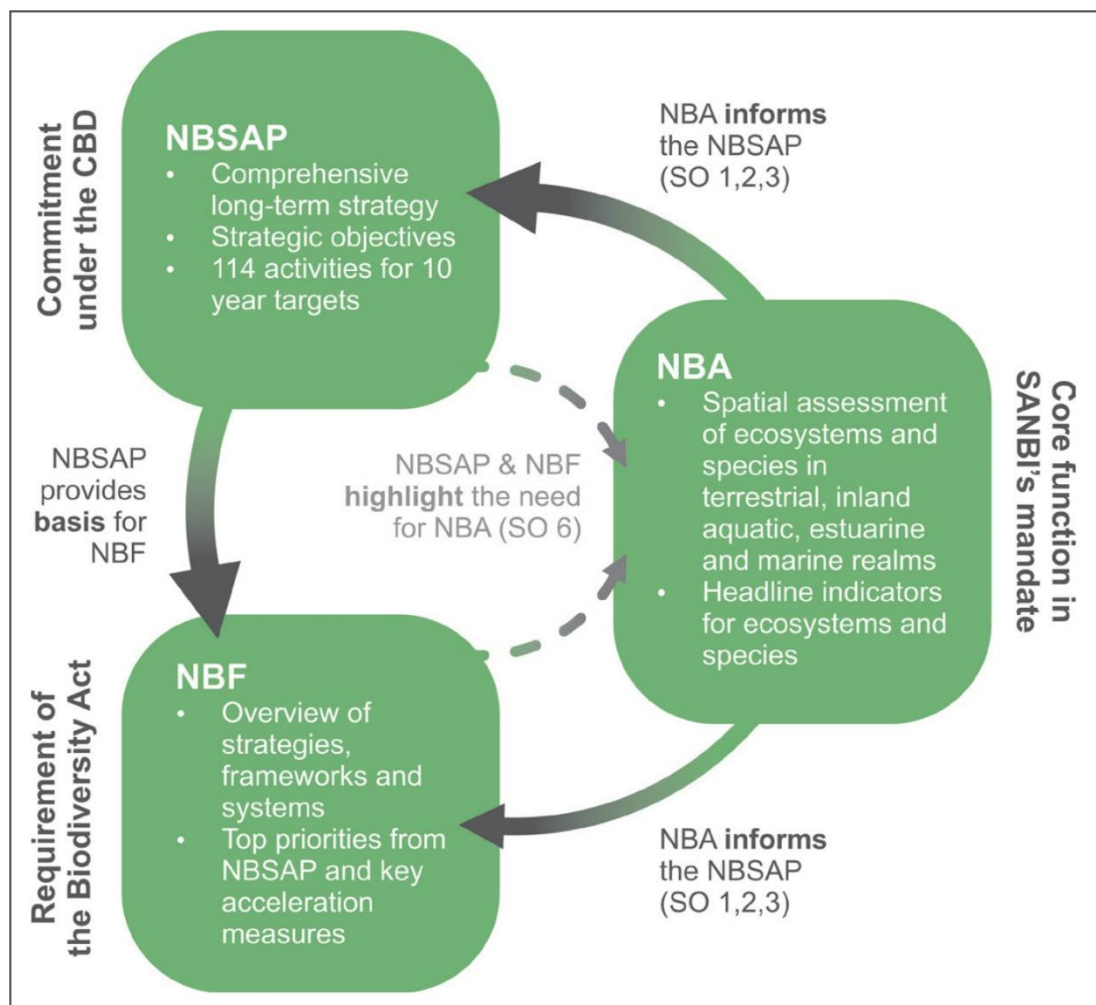


Figure 40. The NBSAP, NBF and NBA together provide key anchors for the work of the biodiversity sector. The NBA synthesises best available science to inform the development and implementation of the NBSAP and NBF. Strategic Objectives (SO).

The NBA directly supports the implementation of Strategic Objectives 1, 2 and 3 of the NBSAP and NBF and also has direct links with Strategic Objective 6, while most of the other objectives are also informed or supported by the NBA (Table 17). Strategic Objective 1 focuses on managing biodiversity assets, and includes outcomes related to expanding the protected area network and management of species of special concern. Strategic Objective 2 focuses on maintaining and restoring ecological infrastructure, including key ecological

⁸ The background information in the above two paragraphs is directly from the NBSAP and NBF documents.

infrastructure features highlighted in the NBA. Strategic Objective 3 includes the science-based planning and decision-making tools that the NBA is a major contributor to, including maps of threatened ecosystems which are a key input into land-use planning and environmental authorisations. The NBA headline indicators of Threat Status and Protection Level are key indicators of whether interventions are making progress towards achieving the Outcomes for these Strategic Objectives. Several of the Outcomes and activities in Strategic Objective 6 directly strengthen the NBA – in other words, if relevant foundational datasets are continually being updated through research and monitoring programmes and such data are available, then the indicators in the NBA can be calculated more regularly and with a higher confidence of accuracy.

Table 17. Strategic Objectives and Outcomes in the NBSAP and NBF, with relevant priority actions for the sub-Antarctic territory.

Strategic Objectives	Outcomes
1. Management of biodiversity assets and their contribution to the economy, rural development, job creation and social well-being is enhanced.	1.1. The network of protected areas and conservation areas includes a representative sample of ecosystems and species, and is coherent and effectively managed. 1.2. Species of special concern are sustainably managed. 1.3. The biodiversity economy is expanded, strengthened and transformed to be more inclusive of the rural poor. 1.4. Biodiversity conservation supports the land reform agenda and socio-economic opportunities for communal landowners.
2. Investment in ecological infrastructure enhances resilience and ensures benefits to society.	2.1. Restore, maintain and secure important ecological infrastructure in a way that contributes to rural development, long-term job creation and livelihoods. 2.2. Ecosystem-based adaptation is shown to achieve multiple benefits in the context of sustainable development.
3. Biodiversity considerations are mainstreamed into policies, strategies and practices of a range of sectors.	3.1. Effective science-based tools inform planning and decision making . 3.2. Embed biodiversity considerations into national, provincial and municipal development-planning and monitoring . 3.3. Strengthen and streamline development authorisations and decision making . 3.4. Compliance with authorisations and permits is monitored and enforced. 3.5. Appropriate allocation of resources in key sectors and spheres of government facilitates effective management of biodiversity, especially in biodiversity priority areas. 3.6. Biodiversity considerations are integrated into the development and implementation of policy, legislative and other tools.
4. People are mobilised to adopt practices that sustain the long-term benefits of biodiversity.	4.1. People's awareness of the value of biodiversity is enhanced through more effective coordination and messaging. 4.2. People are mobilised to conserve and sustainably use biodiversity.
Conservation and management of biodiversity is improved through the development of an equitable and suitably skilled workforce .	5.1. Macro-level conditions enabled for skills planning, development and evaluation of the sector as a whole. 5.2. An improved skills development system incorporates the needs of the biodiversity sector. 5.3. Partnerships are developed and institutions are capacitated to deliver on their mandates towards improved service delivery.
6. Effective knowledge foundations , including indigenous knowledge and citizen science, support the management, conservation and sustainable use of biodiversity.	6.1. Relevant foundational data sets on species and ecosystems are in place and well-monitored and available to the public in a useful format. 6.2. The status of species and ecosystems is regularly monitored and assessed and communicated. 6.3. Geographic priority areas for the management, conservation and restoration of biodiversity assets and ecological infrastructure are identified based on best available science. 6.4. Management-relevant and policy-relevant research and analysis is undertaken through collaboration between scientists and practitioners. 6.5. Knowledge base is accessible and presented in a way that informs decision making .

Key findings

South Africa's sub-Antarctic territory has unique terrestrial and marine ecosystem types that are not found on the mainland or in its surrounding oceans. The iconic Prince Edward Islands (PEIs) support a wide diversity of marine and terrestrial life, providing sanctuary for globally threatened seabirds. Decades of research conducted at the PEIs by a multitude of organisations have placed South Africa at the forefront of sub-

Antarctic and Antarctic science, and highlight the role of the PEIs as a natural laboratory for global change studies. Here we present the key findings for the first assessment of sub-Antarctic biodiversity, an important addition to the NBA 2018.

A first map of 34 ecosystem types in South Africa's sub-Antarctic territory was developed for this assessment. On the islands, **five terrestrial ecosystem types** have previously been mapped and classified in the two biomes: sub-Antarctic Tundra and Polar Desert. Challenges remain in mapping these types at an appropriate scale that both accounts for their spatial complexity and facilitates ecosystem assessment using an international approach. The first map of **29 marine ecosystem types** nested within four benthic-pelagic ecoregions was produced to address a long recognised research priority to include the more than 475 000 km² sub-Antarctic territory in the marine biodiversity assessment. As in the coast of mainland South Africa, these marine and adjacent terrestrial ecosystem types, align seamlessly at the land-sea interface. The marine ecosystem classification and map was based on extensive research, consolidating historical and current information on benthic and pelagic ecoregions. These included long-term positions of major oceanographic frontal systems, research on bathymetry and the seabed, and biodiversity patterns. The new marine ecosystem types include shore types, shelf types, as well as ecosystem types of the slope, plateau, ridges, seamounts, rift valleys and abyss. The classification thus encompasses regionally influential major oceanographic and geomorphological features like the Southwest Indian Ridge, major ocean frontal systems and shallow seamounts. Additional fine-scale descriptive elements of the classification were developed to delineate kelp habitats, areas of pelagic habitat importance for top predator foraging, and the distribution of Vulnerable Marine Ecosystem (VME) indicator taxa. The majority of the terrestrial and marine ecosystem types described are likely to occur on and around other sub-Antarctic islands, indicating the need for collaborative regional work in ecosystem classification and mapping.

South Africa's sub-Antarctic territory supports abundant marine and terrestrial biodiversity and provides critical breeding grounds for seals and globally threatened seabirds. Except for birds and prominent marine mammals, dedicated species assessments have not been conducted for the PEIs, as few taxa are endemic to the PEIs and very limited foundational data are available to conduct species threat assessments. Birds were assessed as part of the marine assessment for the mainland since those species occurring on the islands also frequent South Africa's mainland waters. There are four species of penguins, five species of albatross, 14 species of petrels, one terrestrial bird and five other seabird species, as well as three seal species that breed on the island. **Of the 29 bird species that breed at the PEIs, 28 are Threatened or Near Threatened.** Species assessments were not possible for plant and invertebrate species in this first assessment due to insufficient data, with a large percentage of plant species also being regional endemics, thus their entire distribution would need consideration. While the limited evidence suggests that genetic diversity is surprisingly high in the terrestrial ecosystems of the PEIs, data limitations are a challenge in assessing genetic diversity. Furthermore, research on the ocean shelf ecosystems has recorded highly diverse assemblages on the seabed, and many of these species have potential for bioprospecting.

The first national assessment of the Ecosystem Threat Status of the sub-Antarctic found that 6 of 34 ecosystem types are Threatened and all five terrestrial ecosystem types are Data Deficient. The terrestrial ecosystem types do not experience the direct pressures of the mainland ecosystems, however biological invasions and climate change are the key pressures. Both of these pressures are the subject of ongoing research and a preliminary regional assessment will be possible in the near future. A total of **21% of marine types are threatened by historical or current fishing, including one Endangered ecosystem type (PEI sub-Antarctic Shallow Spreading Ridge) and five Vulnerable ecosystem types** (PEI sub-Antarctic Mid Slope, PEI sub-Antarctic Shallow Seamount, PEI sub-Antarctic Shelf Edge, PEI sub-Antarctic Upper Slope, PEI sub-Antarctic Upper Spreading Ridge). Five Terrestrial and 29 marine ecosystems were assessed using the

International Union for Conservation of Nature (IUCN) Red List of Ecosystems (RLE) guidelines. The IUCN RLE is a framework for assessing the risks to ecosystems and identifying where ecosystems are threatened. This first attempt at a national assessment in the sub-Antarctic territory has highlighted key knowledge gaps and research priorities for future assessments.

A first assessment of Ecosystem Protection Levels was completed for both terrestrial and marine ecosystems. **All five of the terrestrial ecosystem types are Well Protected** in the Special Nature Reserve and RAMSAR Wetland of International Importance. **Thirty-six per cent of South Africa's sub-Antarctic territory is included in the Marine Protected Area (MPA), but only six percent is zoned to exclude fishing for the commercially important Patagonian Toothfish.** Overall, 86% of marine ecosystem types are afforded some protection. The first assessment of Ecosystem Protection Levels revealed that 10 of 29 (34%) marine ecosystems are Well Protected, 14 are Moderately Protected, one is Poorly Protected and four are Not Protected. For the marine realm, there are no ecosystem types that are both highly threatened (or Vulnerable) and Not Protected. The PEI sub-Antarctic Shelf Edge, Mid Slope and Upper Slope are Vulnerable due to historical fishing but are now Well Protected by the territorial sea that excludes fishing around the PEIs. The PEI Shallow Seamount and Upper Spreading Ridge ecosystem types are Vulnerable but Moderately Protected. **The PEI sub-Antarctic Shallow Spreading Ridge is Endangered and fished over its entire extent.** Regional assessments are needed to better understand Protection Levels for those ecosystem types that also occur outside of South Africa's territory in the sub-Antarctic.

The Patagonian Toothfish (*Dissostichus eleginoides*) fishery is a key pressure in the marine environment of the PEIs. Biodiversity concerns associated with the fishery include historical overfishing, stock status concerns, interactions with seabirds and marine mammals and longline impacts to the seabed particularly for Vulnerable Marine Ecosystems (VMEs). The intensity and extent of longline fishing for Patagonian Toothfish was mapped using data available since the experimental fishery began in 1996. The total number of hooks set (fishing effort) was used to map the fishing footprint between 1996 and 2016. Although the original design of the PEI Marine Protected Area recommended the exclusion of fishing for Patagonian Toothfish from four restricted zones, toothfish longlining is permitted in two of the three restricted zones where toothfish occur.

Invasive species are a key threat to sub-Antarctic biodiversity, however South Africa is poised to conduct the largest island-wide rodent eradication of the key invasive species: the House Mouse. Currently there are 26 reported alien invertebrates, one alien vertebrate and 17 alien plant species – many of which have become invasive – that have severely impacted the ecology of the islands. The fastest spreading invasive plant species is *Sagina procumbens*, outcompeting native plant species and compounding impacts of alien invertebrates by increasing their abundance. Nine alien plant species have been effectively controlled since 2012 and ongoing research is being conducted on these and other species to better understand their impacts and inform appropriate control measures. The most profound impact on native biodiversity has been due to the invasive House Mouse, their numbers on Marion Island increasing by 430% at peak density over the last 30 years. This invasive species has substantially decreased invertebrate abundance and plant seed stock, and preys on seabird chicks and eggs. The burrowing activity of mice has directly impacted indigenous plants, causing mortality in a keystone species, *Azorella selago*, a foundational cushion plant species on the island, without which many of the island's biota would not be able to survive in some of the harsher environments. The House Mouse's excessive predation on terrestrial invertebrates has caused a considerable decline in the invertebrate-feeding, endemic Lesser Sheathbill, the islands' only terrestrial bird. The impacts of mice have knock-on ecosystem-level effects, such as decreased decomposition and nutrient cycling as a result of heavy predation on the invertebrates that are an integral component of decomposition at the island – thereby affecting ecosystem structure and functioning. Plans to eradicate mice, using the most humane and least

ecologically destructive methods available, from Marion Island are well developed and South Africa is poised to conduct the largest ever island rodent eradication operation. The impact of marine invasives is unknown due to limited research on this important topic in marine ecosystems, however, marine invasions are an emerging concern as introduced marine taxa have been detected at other sub-Antarctic islands.

Climate change is a serious threat to sub-Antarctic biodiversity with mean annual air and sea temperatures increasing at twice the mean global rate. Warming has directly impacted the ecology of many terrestrial taxa, which evolved under a cool and wet sub-Antarctic climate. Impacts on native species include range expansions, especially to higher (and thus cooler) altitudes. Warmer conditions have exacerbated the spread of alien invasive species and compounded their negative effect on native species, which is expected to worsen with continued warming. Rainfall has decreased by 34% over the past 50 years with warmer air temperatures and more northerly winds coinciding with a considerable drying of the islands. This has directly impacted the ecology of many terrestrial taxa and altered the amount of freshwater flow to the ocean, potentially reducing runoff of bird guano and associated nutrients into coastal ecosystems. Changes in the marine environment at the PEIs are largely driven by the Antarctic Circumpolar Current and its associated fronts, particularly the Sub-Antarctic Front. Warmer waters and faster currents linked to the southward movement of the Sub-Antarctic Front have become more common, reducing local productivity and changing the trophic structure and composition of benthic communities. Epipelagic communities near the islands have changed in species composition, with Antarctic species decreasing and sub-Tropical species becoming more common. As the Antarctic Circumpolar Current and its associated fronts are predicted to migrate poleward, eddy generation at the Southwest Indian Ridge is expected to decrease, reducing the advection of zooplankton and micronekton to the PEIs. The implications of these changes have been most apparent in short to medium-range pelagic predators including Gentoo, Macaroni and Rockhopper Penguins and the Crozet Shag, which have declined in recent decades.

Decades of research conducted at the PEIs by a network of institutions, have placed South Africa at the forefront of sub-Antarctic and Antarctic science, and highlight the role of the PEIs as a natural laboratory for global change studies. The upgraded scientific base on Marion Island and the dedicated Antarctic research vessel, the *SA Agulhas II*, has allowed scientists to conduct novel research on the island systems. Including the sub-Antarctic in the NBA provides a valuable addition for regular reporting of past and current research at the islands, which could ultimately contribute to the management and protection of their unique biodiversity. This first attempt at a national ecosystem assessment highlights knowledge gaps and research priorities for the sub-Antarctic research community. Addressing these priorities will strengthen the science and provide an increasingly effective baseline for the assessment and management of biodiversity in our southernmost territory.

Priority Actions

Five top priority actions were identified to address the key findings of this assessment with links to existing policy, plans and frameworks from the NBA 2018. These priorities were distilled by detailing recommended actions per key finding and by considering these in the context of the strategic objectives of the NBSAP and NBF. These key priorities are listed below with further details per action provided. It is important to recognise that these actions are equally important and not the only actions that may be required, but are a current priority to manage and conserve the biodiversity. They span the knowledge-action continuum and cover a range of actions to improve ecosystem and species status and avoid further ecosystem degradation and impacts on priority species.

The five most urgent priority actions for terrestrial and marine biodiversity in South Africa's sub-Antarctic territory are:

- **Eradicate the invasive House Mouse from Marion Island**
- **Prevent future biological invasions**
- **Reduce fishing impacts in the Prince Edward Islands Marine Protected Area**
- **Maintain and increase time series for critical climate and global change research and manage for climate resilience**
- **Address critical knowledge gaps that limit the assessment of sub-Antarctic biodiversity**

Eradicate the invasive House Mouse from Marion Island

Of the two largest threats facing the PEIs – climate change and biological invasions (Frenot *et al.* 2005, Greve *et al.* 2017) – only the latter can be avoided, controlled or combatted at the island scale. Firstly, **eradicating the House Mouse** is crucial to avoid further ecological changes and possible species extinctions (Dilley *et al.* 2015, McClelland *et al.* 2018). The eradication is considered feasible, while the eradication methods will incorporate the most ethical methods that pose the least risk to the biota at the PEIs and is scheduled to occur in 2021 (Parkes 2016, Preston *et al.* 2019). South Africa has committed to eradicating the mice in a collaborative effort led by the Department of Environment, Forestry and Fisheries, BirdLife South Africa and the Fitzpatrick Institute of African Ornithology. When completed, this will be the largest island-wide eradication of rodents in the world (visit www.mousefreemarion.org.za for more detail). This is the highest priority for invasive species management in our sub-Antarctic territory. Eradicating mice from Marion Island will reduce the degradation of terrestrial ecosystems thereby improving ecosystem condition, function and Threat Status; reduce mortality of plant, invertebrate and threatened seabird species, as well as declines in the endemic Lesser Sheathbill, the islands' only terrestrial bird. This action directly supports the implementation of the NBSAP and NBF, especially Strategic Objectives 1 (Management of biodiversity assets) and 2 (Investment in Ecological Infrastructure).

Prevent future biological invasions

Island ecosystems and species are among the most sensitive to the impact of invasive species (Russel *et al.* 2017). Eradication of invasive species is a time-consuming and costly endeavour, and thus preventing introduction is the best method to avoid further biological invasions. The status of the PEIs as a Special Nature Reserve means that bio-security measures are in place to reduce the potential for further invasions. Such measures have been in place since the 1990s and have been effective in reducing new introductions (DEA 2010). For example, the annual boot washing ceremony, where footwear is inspected and thoroughly cleaned before arriving at the PEIs, has been implemented to reduce the spread of propagules to the islands via clothing (DEA 2010, Greve *et al.* 2017). Some monitoring of alien species is also taking place, as is set out in the DEA management plan for the islands (DEA 2012). It is important that regulations are informed by continued research in this field, which has recently been more highly prioritised, so that control measures may be used appropriately and species with negative impacts on native biota may be targeted.

Ensuring proper implementation of the regulations is a key overarching tool for successful alien and invasive species prevention and control. If policies are not implemented adequately and/or adopted by the research community, invasive species management may fail (McGeoch *et al.* 2015). Proper implementation of biosecurity measures would include regular monitoring of the research activity's adherence to regulations,

with penalties to those that don't comply. This action directly supports the implementation Strategic Objectives 1 (Management of biodiversity assets) and 2 (Investment in Ecological Infrastructure) of the NBSAP and NBF.

Reduce fishing impacts in the PEI Marine Protected Area

The establishment of the Prince Edward Island Marine Protected Area (MPA) in 2013 was intended to contribute to the recovery of Patagonian Toothfish populations, as well as provide protection for vulnerable and unique species and habitats (Lombard *et al.* 2007, WWF 2010). Although 36% of the marine realm of South Africa's sub-Antarctic territory falls within the MPA, only 6% excludes fishing with a set number of hooks per year specified in three of the restricted areas. The impact of fishing in the MPA should be reduced and regulations specifying fishing effort (hook numbers) in restricted zones should be re-evaluated. There is no available documentation regarding the rationale for the hook numbers set within the three restricted zones of the PEI MPA with 650 000 hooks permitted per year in the PEI zone, 450 000 hooks permitted per year in the AR zone and 250 000 hooks per year permitted in the SIR zone. The AB zone excludes fishing but toothfish are not known to occur within the abyssal ecosystem types that receive protection within this restricted zone.

The Prince Edward Islands MPA was declared in April 2013.

"The new MPA is intended, among other things, to contribute to the protection of unique species, habitats and ecosystem processes. It will also provide scientific reference points that can inform the future management of the area and to be able to understand better the impacts of climate change on the whole Southern Ocean. It will also contribute to integrated and ecologically sustainable management of marine resources of the area."

-Late Minister Edna Molewa, Department of Environmental Affairs, April 2013

This action calls to exclude or reduce fishing activity in relevant areas to improve and maintain the protection of marine ecosystem types. In particular, it is important that fishing activity is removed or reduced in the restricted zones and threatened ecosystems, including the PEI sub-Antarctic Shallow Spreading Ridge, PEI Shelf Edge, PEI Upper Slope and PEI Mid Slope, PEI Shallow Seamount and PEI Upper Spreading Ridge ecosystem types. In addition, South Africa should increase regional collaboration in compliance and enforcement effort and encourage further innovation and the application of new technology to address IUU fishing. The 100% observer coverage on toothfish fishing vessels should be maintained. These actions are particularly important for the implementation of Strategic Objectives 1 (Management of biodiversity assets) and 3 (Mainstreaming of Biodiversity Considerations).



The SA Agulhas replenishes Marion Island Base's fuel stocks for the upcoming overwintering season. Photo: Robyn Adams

Maintain and increase critical climate and global change time series research and manage for climate resilience

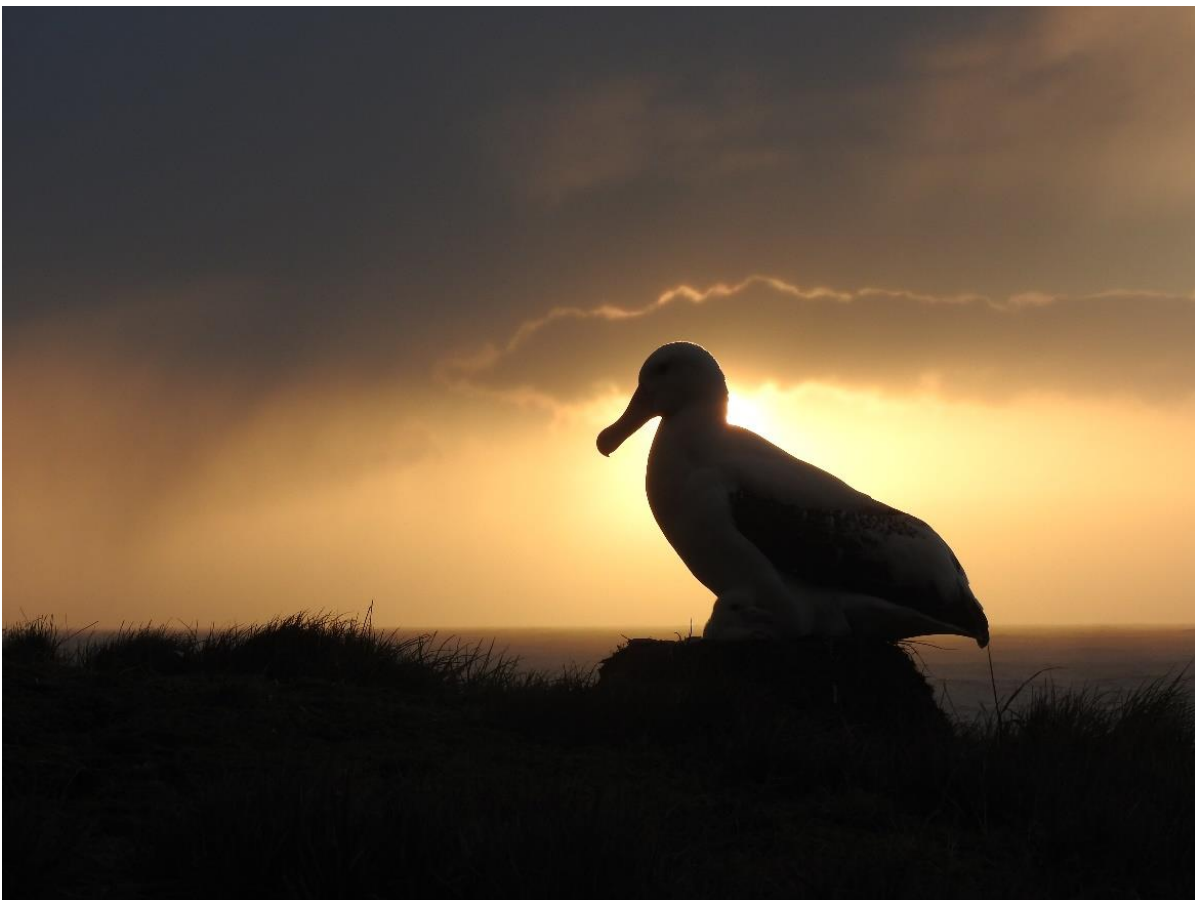
South Africa has a long history of research that has made global contributions to the understanding of climate change. Long term data sets provide critical information to detect change and increase our understanding of global change impacts to better predict future changes and degradation of ecosystems, providing the ability to apply adaptive management of our biodiversity assets. Since the Southern Ocean is critical in the global carbon cycle and the climate is changing faster in the Southern Ocean than many other regions, the role of our sub-Antarctic climate research is increasingly important and provides the opportunity for South Africa to be at the forefront of understanding, predicting and mitigating climate change impacts. From a biodiversity perspective, the impacts of climate change on all native biota must be understood to conserve and manage ecosystems in the sub-Antarctic. Furthermore, understanding the interaction between climate change, fishing and invasive species impacts should be prioritised, as their compounding effect may cause more rapid degradation of ecosystems, than would their separate impacts. Therefore, understanding, managing and reducing the more direct pressures of invasive species and fishing may help mitigate climate change impacts.

In addition to research to track and understand climate change, there are also clear recommendations to improve climate resilience. Although it is difficult to directly mitigate the impacts of and increase resilience to climate change in the sub-Antarctic, maintaining the health of ecosystems and improving ecosystem condition can help mitigate the effects of climate change. Consequently, terrestrial ecosystems must be managed to decrease degradation by minimising human impacts and taking action to restore ecosystem condition where possible, such as the eradication of the invasive House Mouse, without which may

compound the impacts of climate change. Reducing the impacts of mice, may increase the resilience of species and ecosystems to climate change by decreasing the mice's contribution to ecosystem degradation. Fishing impacts in the PEI Marine Protected Area should be reduced and effective collaborative compliance efforts maintained and strengthened through additional international co-operation. Reducing the effects of legal and illegal fishing can help marine ecosystems and species to be more resilient to climate-driven changes. This is particularly important if the fishing activity in the Southern Ocean increases. Further critical biodiversity areas within the sub-Antarctic territory and beyond the EEZ should be identified and protected, which may be achieved through collaborative conservation planning initiatives and agreements with countries that share common objectives in the Indian Ocean sector of the Southern Ocean, such as France and Australia.

In addition, a key aspect of this action is to raise awareness of our sub-Antarctic territory and its important role in the global carbon cycle, and how this may contribute to climate change mitigation. A priority is to ensure that the NBA results are communicated to decision-makers and managers for the development of detailed plans to improve climate change resilience at the PEIs. Additionally, South Africa must engage in regional efforts to improve monitoring and mitigation of climate change in the sub-Antarctic.

This priority action directly supports the implementation of Strategic Objectives 1 (Management of biodiversity assets), 2 (Investment in ecological infrastructure) and 3 (Mainstreaming of Biodiversity Considerations) of the NBSAP and NBF and also has direct links with Strategic Objective 6.3 (Geographic priority areas for the management, conservation and restoration of biodiversity assets) and 6.5 (Knowledge base is accessible and presented in a way that informs decision making).



A Wandering albatross resting on its nest on Marion Island. Photo: Stephni van der Merwe

Address critical knowledge gaps that limit the assessment of sub-Antarctic biodiversity

Key limitations in the 2018 assessment include foundational data gaps for ecosystems, species and genes, insufficient data and understanding of the impact of some pressures and interactions between pressures, limited experience regarding the appropriate scale and thresholds for marine ecosystem assessments, as well as challenges in assessing species distributions, the extent of ecosystem degradation and hence the Threat Status of terrestrial ecosystems and species. These research priorities are further detailed in Table 19 below. This priority action addresses Strategic Objective 6 (Knowledge foundations) of the NBSAP and NBF (Table 17). Improving foundational knowledge will improve the quality of assessments and reduce uncertainty in results. Building assessment capacity and addressing knowledge gaps can also support NBSAP and NBF Strategic Objective 5 (Developing an equitable and suitable skilled work force to improve biodiversity management). As the only African country with sub-Antarctic territory, South Africa must maintain its high standard of research and opportunities for scientific capacity development. Increased international collaboration may offer opportunities for further capacity development but South Africa's emerging researchers are also well positioned to use local research infrastructure to address key gaps while developing their careers in Southern Ocean Research. A business as usual approach is unlikely to succeed in addressing these critical knowledge gaps timeously. Innovation, increased international collaboration and dedicated new research projects are key elements in meeting this challenge. Addressing these knowledge gaps will strengthen future assessments, reduce uncertainty and help direct critical interventions to maintain biodiversity benefits into the future.

Implementing these five priority actions can contribute to addressing the key findings of this report particularly in terms of the main biodiversity concerns in South Africa's sub-Antarctic territory. Implementing these actions will help reduce pressures on threatened and degraded ecosystems and threatened species, restore and maintain ecosystem services and can help maintain and increase biodiversity benefits in the Southern Ocean.

Further priority actions

Whereas the Antarctic and sub-Antarctic regions have generally been considered as pristine environments where outbreaks of diseases are not of much concern, given assumed isolation from lower latitude sources of infection or pollution (Grimaldi *et al.* 2011), uncommon disease outbreaks have become more prevalent (e.g. Cooper *et al.* 2009). Increased human presence (Grimaldi *et al.* 2011) and climate changes (Harvell *et al.* 1999) are factors which may influence this by reducing barriers to the spread of pathogens and compounding the vulnerability (through stress) of individuals and populations to disease outbreaks. Indeed, stress from climatic changes is predicted to exacerbate the vulnerability of migratory birds, mammals and higher predators to infectious diseases (IPCC 2007). At remote locations such as the Prince Edward Islands, the size and density of seabird and seal colonies (Crawford *et al.* 2003c, Wege *et al.* 2016) can facilitate rapid transmission of infectious agents between individuals and have the potential to result in large epizootics (Bonnedahl *et al.* 2005). Although such a disease outbreak could decimate a population, the true costs of disease can also be associated with chronic attrition of the population (Friend *et al.* 2001) and thereby influence metabolic rates, life history traits and social status (Barbosa and Palacios 2009). Therefore, disease can have severe implications for wildlife populations of the Prince Edward Islands, where many populations are already dwindling or are threatened in terms of conservation status. While there is increasing recognition that understanding of health and disease and related impacts on wildlife populations is essential to support effective conservation and management decisions (Hall *et al.* 2010), an overall understanding of the presence and extent of diseases at these islands, and potential risks posed by disease outbreaks, are lacking – so far disease research at the island has not been systematic and has been conducted only in response to apparent

disease outbreaks (e.g. De Bruyn *et al.* 2008, Cooper *et al.* 2009), or has focused only upon particular animals or agents of infection. The first step to understanding the basic disease ecology and risks to the resident wildlife populations and ecosystem, will be to systematically **obtain baseline data on occurrence of disease agents in multiple species and the environment**. Such a baseline will set the standards for long term monitoring of wildlife health and disease at the islands, detection, prevention (e.g. improved biosecurity measures), control and mitigation, and should be a priority for future research.

A key aspect of mobilising resources and management action to address these priorities includes the need to **effectively communicate the value of South Africa's sub-Antarctic biodiversity** through improved co-ordinated messaging that articulates the biodiversity benefits, in this globally important region, especially it's critical role in the global carbon cycle and potential to improve our understanding of climate change mitigation. These benefits include carbon sequestration and climate regulation, fisheries benefits, bio-discovery potential and the valuable research assets that are provided by this natural laboratory that can help understand global change. The need for increased effort in identifying, quantifying and communicating the benefits and value of biodiversity has been recognised in all realms in the NBA (Skowno *et al.* 2019). This is the core of Strategic Objective 4 of the NBSAP and NBF which emphasises the need to mobilise people to adopt more sustainable practices. Improved awareness of the role of biodiversity in the everyday lives of people is needed and better communication of these benefits can help adjust behaviour. In this regard, the ongoing collection of data on biodiversity benefits, with a focus on jobs and economic value, is a high priority. This is essential for the effective implementation of Strategic Objective 4 of the NBSAP and NBF. Sub-Antarctic biodiversity benefits require more explicit consideration in biodiversity assessment, emerging regional conservation planning initiatives and Marine Spatial Planning.

Table 18. Priority actions for improving the state of sub-Antarctic biodiversity and their links to Strategic Objectives in the NBSAP and NBF.

Strategic Objectives	Priority Actions for the sub-Antarctic
1. Management of biodiversity assets and their contribution to the economy, rural development, job creation and social well-being is enhanced.	- Strengthen marine protection to advance marine ecosystem types towards Well Protected. Reduce the impact of fishing in the Restricted zones of the MPA through re-zonation and review of hook limits in Restricted zones. - Eradicate mice from Marion Island to improve ecosystem condition, reduce degradation and reduce impacts on other species including threatened seabirds. - Prevent future invasions through work to identify potential invasives, strategic monitoring across environments, improved measures to reduce the risk of introductions and planning for management action - Support recovery of toothfish
2. Investment in ecological infrastructure enhances resilience and ensures benefits to society.	- Raise awareness of the important role played by South Africa's sub-Antarctic territory in the global carbon cycle, and how this contributes to climate change mitigation. - Implement stock recovery initiatives for toothfish and maintain benefits from fishery through effective fishery management to ensure sustainability.
3. Biodiversity considerations are mainstreamed into policies, strategies and practices of a range of sectors.	- Ensure NBA results are communicated to decision-makers and managers for the development of detailed plans to improve Ecosystem Threat Status and Protection Level. - Ensure mice eradication program is well resourced and effectively implemented. - Increase engagement in regional efforts to improve monitoring, control and surveillance in the sub-Antarctic.
4. People are mobilised to adopt practices that sustain the long-term benefits of biodiversity.	- Raise awareness of South Africa's sub-Antarctic biodiversity and its benefits including climate regulation, fisheries, biodiversity, tourism potential and research opportunities, as well as invoke pride. - Mobilise support for the eradication of mice on Marion Island via crowdfunding initiatives such as Mouse Free Marion.
5. Conservation and management of biodiversity is improved through the development of an equitable and suitably skilled workforce.	- As the only African country with sub-Antarctic territory, South Africa must continue to maintain its high standard of research and opportunities for scientific capacity development. - Establish new regional partnerships that can help increase South Africa's capacity to undertake research and effectively manage this globally significant region. - Participate in regional initiatives to better understand the distribution, endemism and condition of terrestrial and marine ecosystem types in the region.
6. Effective knowledge foundations , including indigenous knowledge and citizen science, support the management, conservation and sustainable use of biodiversity.	- Increase foundational research to support species and ecosystem classification and assessment and detection of alien and invasive species - Improve ecosystem condition data and knowledge on the impacts of invasive species - Assess Threat Status of terrestrial ecosystem types - Maintain and increase critical long term data sets to detect and monitor climate change, taking full advantage of the role of the PEIs as a natural laboratory for global change studies. - Support closer co-operation between scientists and policy makers to improve biodiversity management. - Improve access to long-term datasets to facilitate new research, broaden participation in research and application of key recommendations emerging from research results.

Knowledge gaps

The key knowledge gaps and limitations from this assessment were identified in the relevant chapters above and are summarised below (also see Table 19). Research priorities span foundational biodiversity research at the ecosystem, species and genetic level; research to improve the understanding of key pressures and ecosystem condition, and monitoring priorities. Addressing these gaps will help improve future biodiversity assessments, improving confidence and reducing uncertainty to effectively inform policy, management and action for improvements in the status of sub-Antarctic biodiversity.

Priority **foundational biodiversity research** includes a better understanding of the regional extent of both marine and terrestrial ecosystem types. Endemic ecosystem types must be identified and prioritised. Regional Threat Status and Protection Level assessments are needed to prioritise management interventions

for ecosystem types that have extensive distributions outside of South Africa's territory. Species and genetic assessments are a further priority with insufficient information and resources to systematically address these biodiversity components in the NBA 2018.

While our understanding of the PEIs' ecosystems and some species has developed substantially over the last few decades, there is considerable room for improving knowledge of **ecological condition** and **species population trends**, especially under accelerated climate change. Human disturbance from research activities (Wheeler *et al.* 2009) should be considered in future assessments. Most species assessments could not be conducted due to limited population trend data. Furthermore, genetic assessments could also not be conducted and remains a knowledge gap to address in future biodiversity assessments. Further work to define and understand key foraging areas of the apex predators in the system is a key priority to support regional efforts to plan effective spatial management networks including MPAs in the Southern Ocean.

Substantial research gaps hamper the ability to understand and manage the impacts of **invasive species**. Some taxa have received no attention, and the impact of invasive species is not well understood (Greve *et al.* 2019). The impacts of the House Mouse and *Sagina procumbens* on native biota are particularly important to understand, as they are the most widespread invasive species. It is crucial to improve our mapping and monitoring of the distribution and abundance of invasive species so that their impacts on indigenous species and ecosystems can be reliably modelled. Furthermore, for future biodiversity assessments, understanding the impacts of invasive species, and not only their spread, is recommended as a high priority for research endeavours. Developing a watch list of potential invaders would be useful.

Many data gaps exist that limit the ability to assess ecosystem condition and the vulnerability of ecosystems to **climate change**. Current monitoring of indicator species and ecosystems must continue and more must be identified to allow researchers to better detect and understand the impacts of climate change on biodiversity. The lack of uninterrupted island-wide abiotic data (such as rainfall and wind) inhibits monitoring and future predictions of climate change in terrestrial ecosystems. Many data gaps in marine ecosystems relate to limited *in situ* biological sampling due to logistical constraints. While physical ocean processes and top predator foraging can be studied remotely using satellites and tracking devices, lower to mid-trophic level organisms such as krill and mesopelagic fish require logistical support for *in situ* sampling. Biological sampling near the PEIs has been largely restricted to the annual relief voyage in April/May and therefore the seasonal dynamics of benthic and pelagic communities is not well understood. Improved spatiotemporal monitoring of physical conditions, and zooplankton and micronekton communities is needed to improve models that allow the prediction of future impacts of climate-driven changes to pelagic food webs and carbon cycling. The vital role of the Southern Ocean in the global carbon budget stresses the importance of understanding changes in the biogeochemical and ecological processes underlying sub-Antarctic ecosystems.

Table 19. Knowledge gaps and research priorities identified during the NBA 2018 assessment for the sub-Antarctic.

Knowledge gap causing limitation to the NBA	Research Priorities
The regional context of terrestrial and marine ecosystem types in the sub-Antarctic is not well understood.	Dedicated research is needed focusing on mapping and understanding the regional distribution of ecosystem types and species, especially in relation to other islands such as the nearby Crozet Islands. This may provide the opportunity for collaboration between sub-Antarctic programmes and institutions, as well as other countries.
Gaps in ecological condition data and insufficient knowledge of invasive species and climate change impacts led to a Threat Status of Data Deficient for all 5 terrestrial ecosystems at the PEIs.	Measuring and mapping ecological condition of the terrestrial ecosystems. Assessment of ecosystem condition should be conducted, equivalent to the land cover change data set for the mainland, by studying the extent and impact of the two key pressures, biological invasion and climate change, on ecosystem structure, function and composition. Indicators must be applied to track biodiversity change. Ecosystem condition change data and dedicated species population monitoring over time are needed to detect change and inform predictive models in future.
The poor understanding of the impacts of toothfish fishing in terms of ecosystem degradation and a lack of spatial data on climate change impacts reduce certainty in marine ecosystem assessments.	The benthic and International and regional collaboration is encouraged to improve understanding in this regard.
Terrestrial plant and invertebrate species threat assessments have not been conducted for the PEIs.	Determine plant and invertebrate species distribution and abundance at the PEIs, as well as their entire distributions beyond South African territory. There is opportunity to draw from the substantial existing data and expertise for species threat assessments.
The Protection Level indicator for species was not applied for any sub-Antarctic species in the NBA 2018.	The species protection index needs to be tested and refined and applied in the terrestrial and marine realms for our Southern Ocean species.
Insufficient information or resources to initiate any reporting on the genetic component of sub-Antarctic biodiversity.	Further testing of potential metrics to explore the best possible indicators of genetic diversity is needed. Ensure sub-Antarctic species are included in efforts to strategically prioritise taxa for monitoring.
Seasonality of benthic and pelagic communities and biogeochemical change is not well understood as most in situ physical and biological oceanography has been conducted during April and May due to logistical constraints.	Investment in glider deployments in ecologically important areas is needed, i.e. the "conveyor belt" of eddies upstream of the islands that originate at the Southwest Indian Ridge (SWIR) and hotspots identified through predator tracking. Visit these areas in a research vessel to perform biological oceanography.
Shallow shelf habitats (<30 m) are undersampled but are probably the most susceptible benthic environments to changing currents and warming sea temperatures.	Improve sampling during takeover period.
Deep ocean ecosystems are largely unsampled.	Sampling of ecosystem beyond the shelf is encouraged with increased international collaboration encouraged. Opportunities to conduct visual sampling of the deep seabed should be sought. Potential vent habitats should be investigated on the SWIR where petroleum geologists report the presence of both black and white smokers.
Uninterrupted island-wide climate data are lacking.	Deploy weather stations at field huts.
Lack of open source data sharing platforms , particularly climate data.	Create a database repository for sub-Antarctic science or specifically at the Prince Edward Islands.
Contributions of pelagic organisms, particularly mesozooplankton, to carbon flux is not well understood.	New research to understand the role of pelagic biodiversity in climate resilience is encouraged.

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LIST OF ACRONYMS, ABBREVIATIONS, INITIALISMS AND SYMBOLS

a.s.l.	above sea level
ACC	Antarctic Circumpolar Current
ANDEEP	ANtarctic benthic DEEP-sea biodiversity
APF	Antarctic Polar Front
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CR	Critically Endangered
DAFF	Department of Agriculture, Forestry and Fisheries (former government department)
DALRRD	Department of Agriculture, Land Reform and Rural Development (formed by merging DAFF and Department of Rural Development and Land Reform in June 2019)
DEA	Department of Environmental Affairs (former government department)
DEFF	Department of Environment, Forestry and Fisheries (formed by merging DAFF and DEA in June 2019)
DSI	Department of Science and Innovation (new departmental name in June 2019)
DST	Department of Science and Technology (former government department)
DWS	Department of Water and Sanitation
EEZ	Exclusive Economic Zone
EN	Endangered
ESA	European Space Agency
GEBCO	General Bathymetric Chart of the Oceans
GIS	Geographic Information System
IHO	International Hydrographic Organisation
IUCN	International Union for the Conservation of Nature
IUU	Illegal, unreported and unregulated fishing
LC	Least Concern
LWM	Low Water Mark
MADT	Maps of Absolute Dynamic Topography
MPA	Marine Protected Area
mya	million years ago
NBA	National Biodiversity Assessment
NEMPA	National Environmental Management: Protected Areas Act
NSBA	National Spatial Biodiversity assessment
NT	Near Threatened
PEI	Prince Edward Islands
SAF	Sub-Antarctic Front
SANBI	South African National Biodiversity Institute
SST	Sea Surface Temperature
STF	Subtropical Front
SWIR	Southwest Indian Ridge
VME	Vulnerable Marine Ecosystem
VU	Vulnerable

GLOSSARY OF TERMS

Commonly-used terms are not provided for in this glossary, as the lexicon of Biodiversity Planning in South Africa is an important tool that provides standard definitions of key concepts and frequently used terms. The terms below are those that are new for NBA 2018 or those that might cause some confusion.

Biodiversity target: The minimum proportion of each ecosystem type that needs to be kept in a natural or near-natural state in the long term in order to maintain viable representative samples of all ecosystem types and the majority of species associated with those ecosystem types.

Biodiversity thresholds: A series of thresholds used to assess ecosystem Threat Status, expressed as a percentage of the original extent of an ecosystem type. The first threshold, for Critically Endangered ecosystems, is equal to the biodiversity target; the second threshold, for Endangered ecosystems, is equal to the biodiversity target plus 15%; and the third threshold, for Vulnerable ecosystems, is usually set at 60%. Also see Ecosystem Threat Status.

Biodiversity: The diversity of genes, species and ecosystems on Earth, and the ecological and evolutionary processes that maintain this diversity.

Biome: An ecological unit of wide extent, characterised by complexes of plant communities and associated animal communities and ecosystems, and determined mainly by climatic factors and soil types. A biome may extend over large, more or less continuous expanses or land surface, or may exist in small discontinuous patches.

Conservation area: Areas of land not formally protected by law but informally protected by the current owners and users and managed at least partly for biodiversity conservation. Because there is no long-term security associated with conservation areas, they are not considered a strong form of protection. Also see Protected area.

Conservation planning—see Biodiversity planning.

Critical Biodiversity Area: Areas required to meet biodiversity targets for ecosystems, species or ecological processes, as identified in a systematic biodiversity plan. May be terrestrial or aquatic.

Critically Endangered (CR): An ecosystem type is Critically Endangered when the evidence indicates that it meets any of the criteria A to E for CR. It is then considered to be at an extremely high risk of collapse.

Data Deficient (DD): An ecosystem type is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of collapse. DD is not a category of threat and does not imply any level of collapse risk. Listing ecosystems in this category indicates that their situation has been reviewed, but that more information is required to determine their risk status.

Ecosystem Protection Level: Indicator of the extent to which ecosystems are adequately protected or under-protected. Ecosystem types are categorised as Well Protected, Moderately Protected, Poorly Protected, or Not Protected, based on the proportion of the biodiversity target for each ecosystem type that is included within one or more protected areas. Not Protected, Poorly Protected or Moderately Protected ecosystem types are collectively referred to as under-protected ecosystems.

Ecosystem Threat Status: Indicator of how threatened ecosystems are, in other words the degree to which ecosystems are still intact or alternatively losing vital aspects of their structure, function or composition. Ecosystem types are categorised as Critically Endangered, Endangered, Vulnerable or Least Threatened, based on the proportion of the original extent of each ecosystem type that remains in good ecological condition relative to a series of biodiversity thresholds. Critically Endangered, Endangered and Vulnerable ecosystems are collectively referred to as Threatened Ecosystems, and may be listed as such in terms of the Biodiversity Act.

Ecosystem type: An ecosystem unit that has been identified and delineated as part of a hierarchical classification system, based on biotic and/or abiotic factors. Factors used to map and classify ecosystems differ in different environments. Ecosystem types can be defined as, for example, vegetation types, river ecosystem types, wetland ecosystem types, estuary ecosystem types, or marine or coastal habitat types. Ecosystems of the same type are likely to share broadly similar ecological characteristics and functioning. Also see National ecosystem classification system.

Ecosystem-based Adaptation (to climate change): The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change. Includes managing, conserving and restoring ecosystems to buffer humans from the impacts of climate change, rather than relying only on engineered solutions. Combines socio-economic benefits, climate-change adaptation, and biodiversity and ecosystem conservation, contributing to all three of these outcomes simultaneously.

Endangered (EN): An ecosystem type is Endangered when the evidence indicates that it meets any of the criteria A to E for EN, and is then considered to be at a very high risk of collapse.

Least Concern (LC): An ecosystem type that has experienced little or no loss of natural habitat or deterioration in condition.

National ecosystem classification system: A hierarchical system for mapping and classifying ecosystem types in the terrestrial, river, wetland, estuarine, coastal and marine realm. South Africa has a well-established classification system for terrestrial ecosystems in the form of vegetation mapping, and much progress has been made in mapping and classifying aquatic ecosystems as part of the NBA 2011. Factors used to map and classify ecosystems differ in different environments, but in all cases ecosystems of the same type are expected to share broadly similar ecological characteristics and functioning. The national ecosystem classification system provides an essential scientific foundation for ecosystem-level assessment, planning, monitoring and management. Also see Ecosystem type.

Near Threatened (NT): An ecosystem type is Near Threatened when it has been evaluated against the criteria but does not qualify for CR, EN or VU, but it is close to qualifying for or is likely to qualify for a threatened category in the near future.

Not Evaluated (NE): An ecosystem type is Not Evaluated when it has not been assessed against any of the criteria.

Protected area target: A quantitative goal for how much of an ecosystem type should be included in the protected area network by a certain date. The National Protected Area Expansion Strategy 2008 sets five-year and twenty-year protected area targets for each terrestrial ecosystem type, based on a portion of its biodiversity target. Protected area targets are revised every five years.

Protected area: An area of land or sea that is formally protected by law and managed mainly for biodiversity conservation. This is a narrower definition than the IUCN definition, which includes areas that are not legally protected and that would be defined in South Africa as conservation areas rather than protected areas. Also see Conservation area.

Spatial biodiversity plan: A plan that identifies one or more categories of biodiversity priority area, using the principles and methods of systematic biodiversity planning. South Africa has a suite of spatial biodiversity plans at national and sub-national level, which together should inform land-use planning, environmental impact assessment, water resource management, and protected area expansion.

Systematic biodiversity planning: A scientific method for identifying geographic areas of biodiversity importance. It involves: mapping biodiversity features (such as ecosystems, species, spatial components of ecological processes); mapping a range of information related to these biodiversity features and their ecological condition; setting quantitative targets for biodiversity features; analysing the information using software linked to GIS; and developing maps that show spatial biodiversity priorities. The configuration of priority areas is designed to be spatially efficient (i.e. to meet biodiversity targets in the smallest area possible) and to avoid conflict with other land and water resource uses where possible.

Systematic conservation planning—see Systematic biodiversity planning.

Threatened ecosystem: An ecosystem that has been classified as Critically Endangered, Endangered or Vulnerable, based on an analysis of Ecosystem Threat Status. A threatened ecosystem has lost or is losing vital aspects of its structure, function or composition. The Biodiversity Act allows the Minister of Environmental Affairs or a provincial MEC for Environmental Affairs to publish a list of threatened ecosystems. To date, threatened ecosystems have been listed only in the terrestrial environment. In cases where no list has yet been published by the Minister, such as for all aquatic ecosystems, the Ecosystem Threat Status assessment in the NBA can be used as an interim list in planning and decision-making. Also see Ecosystem Threat Status.

Threatened species / ecosystem: A species or ecosystem that has been classified as Critically Endangered, Endangered or Vulnerable, based on a conservation assessment (Red List), using a standard set of criteria developed by the IUCN for determining the likelihood of a species becoming extinct. A threatened species faces a high risk of extinction in the near future.

Vulnerable (VU): An ecosystem type is Vulnerable when the best available evidence indicates that it meets any of the criteria A to E for VU, and is then considered to be at a high risk of collapse.

APPENDICES

Appendix A List of attendees at the Prince Edwards Islands Ecosystem classification workshop held for development of the Prince Edward Islands Ecosystem Classification and Map, 16 August 2017.

Name	Affiliation
Luther Adams	South African National Biodiversity Institute
Maëlle Conan	Nelson Mandela University
John Cooper	Stellenbosch University
Mbulelo Dopolo	Department of Environment, Forestry and Fisheries
Loyiso Dunga	South African National Biodiversity Institute / University of Cape Town/CSIR
Mari-Lise Franken	South African National Biodiversity Institute
William Froneman	Rhodes University
Linda Harris	Nelson Mandela University
Tanya Haupt	Department of Environment, Forestry and Fisheries
Stephen Holness	Nelson Mandela University
Carol Jacobs	Department of Environment, Forestry and Fisheries
Robin Leslie	Department of Environment, Forestry and Fisheries
Amanda Lombard	Nelson Mandela University
Azwianewi Makhado	Department of Environment, Forestry and Fisheries
Maphale Matlala	South African National Biodiversity Institute
Stewart Norman	CAPMARINE
Roxanne Oliver	Department of Environment, Forestry and Fisheries
Herman Oosthuizen	Department of Environment, Forestry and Fisheries
Maya Pfaff	Department of Environment, Forestry and Fisheries
Eleonora Puccinelli	University of Cape Town
Peter Ryan	FitzPatrick Inst. University of Cape Town
Kerry Sink	South African National Biodiversity Institute
Andrew Skowno	South African National Biodiversity Institute
Melanie Smith	CAPMARINE
Charles von der Meden	South African National Biodiversity Institute
Ross Wanless	BirdLife South Africa

Appendix B. The fourteen species of top predator used to map areas of ecological significance. NT = Near Threatened; LC = Least Concern; VU = Vulnerable; EN = Endangered; DD = Data Deficient

Family	Species	Common name	IUCN Global Threat Status
Albatrosses (Diomedidae)	<i>Phoebastria palpebrata</i>	Light-mantled albatross	NT
Albatrosses (Diomedidae)	<i>Phoebastria fusca</i>	Sooty albatross	EN
Albatrosses (Diomedidae)	<i>Thalassarche chrysostoma</i>	Grey-headed albatross	EN
Albatrosses (Diomedidae)	<i>Thalassarche carteri</i>	Indian yellow-nosed albatross	EN
Albatrosses (Diomedidae)	<i>Diomedea exulans</i>	Wandering albatross	VU
Penguins (Spheniscidae)	<i>Aptenodytes patagonicus</i>	King penguin	LC
Penguins (Spheniscidae)	<i>Eudyptes chrysocome</i>	Southern rockhopper penguin	VU
Penguins (Spheniscidae)	<i>Eudyptes chrysolophus</i>	Macaroni penguin	VU
Petrels (Procellariidae)	<i>Procellaria aequinoctialis</i>	White-chinned petrel	VU
Petrels (Procellariidae)	<i>Macronektes halli</i>	Northern giant petrel	LC
Dolphins (Delphinidae)	<i>Orcinus orca</i>	Killer whale	DD
Eared seals (Otariidae)	<i>Arctocephalus gazella</i>	Antarctic fur seal	LC
Eared seals (Otariidae)	<i>Arctocephalus tropicalis</i>	Subantarctic fur seal	LC
True seals (Phocidae)	<i>Mirounga leonina</i>	Southern elephant seal	LC

Appendix C. Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR) classification of taxa indicative of Vulnerable Marine Ecosystems based on scored criteria related to vulnerability to physical disturbance (CCAMLR 2009a).

Taxon	Habitat forming	Rare or unique	Longevity	Slow growth	Fragility	Dispersal potential	Adult immobility
Phylum Porifera							
Hexactinellida	H	L	H	H	H	M	H
Demospongiae	H	M	H	H	H	M	H
Phylum Cnidaria							
Actiniaria	L	L	H	L	L	M	M
Scleractinia	H	M	H	H	H	M	H
Antipatharia	M	L	H	H	H	L	H
Alcyonacea	M	L	M	L	M	M	H
Gorgonacea	M	L	H	H	H	M	H
Pennatulacea	L	H	H	M	H	L	M
Zoanthida	L	L			M	L	H
Hydrozoa							
Hydroidolina	L	L			L		H
Family Stylasteridae	H	L	H	M	H	H	H
Phylum Bryozoa	H	L	H	M	H	H	H
Phylum Echinodermata							
Crinoidea: Stalked crinoid orders	L	H	H		H		H
Echinoidea: Order Cidaroida	M	L	H	H	M	H	L
Ophiuroidea: Basket and snake stars	L	L			H	L	M
Phylum Chordata: Class Ascidiacea	M	L		L	L	L	H
Phylum Brachiopoda	L	H	H	L	M	M	H
Phylum Annelida: Family Serpulidae	M	L			H	L	H
Phylum Arthropoda: Infraclass Cirripedia:							
Bathylasmataidae	L	H	H		M	L	H
Phylum Mollusca: Pectinidae: <i>Adamussium colbecki</i>	L	H	H	M	M	L	M
Phylum Hemichordata: Pterobranchia	M	M			M	H	H
Phylum Xenophyophora	L	H			H		H
Chemosynthetic communities	H	H	H	H	H	L	H

Appendix D. Extended summary of ecosystem type descriptions and related species occurrence for the sub-Antarctic territory marine ecosystem classification.

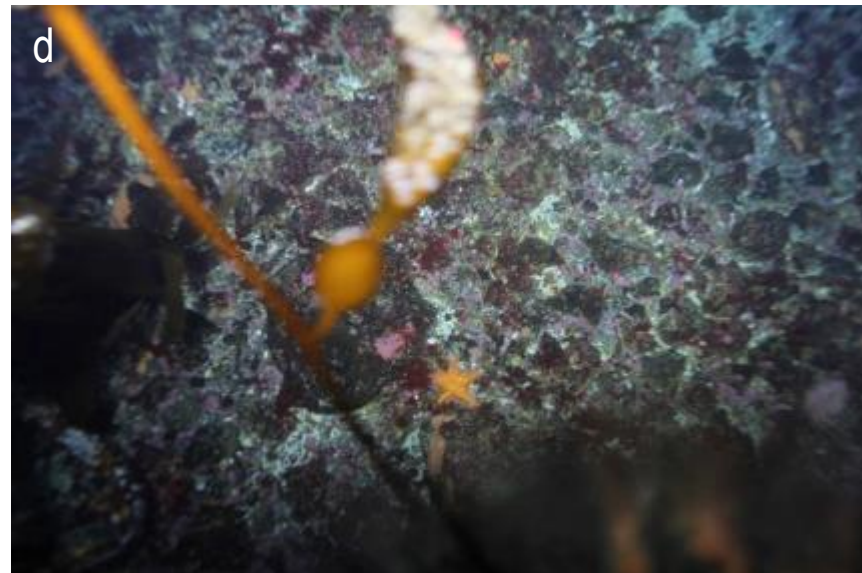
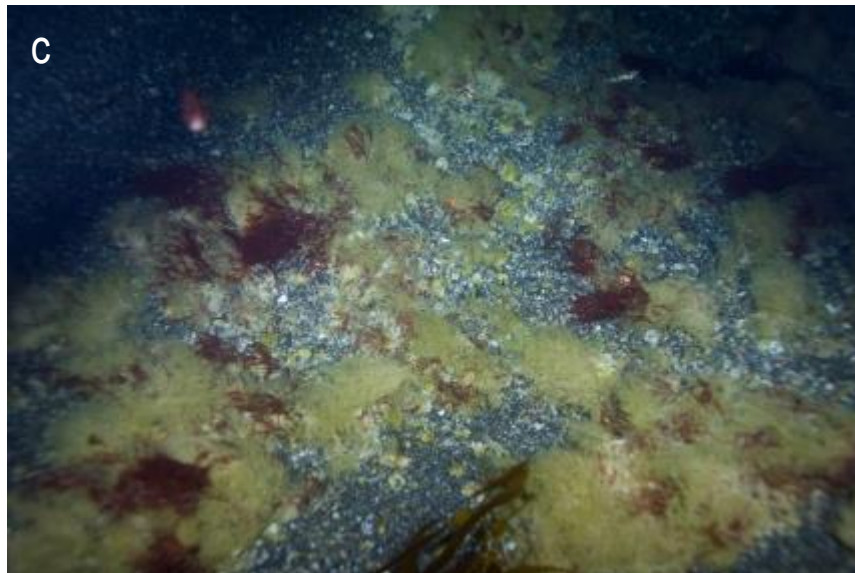
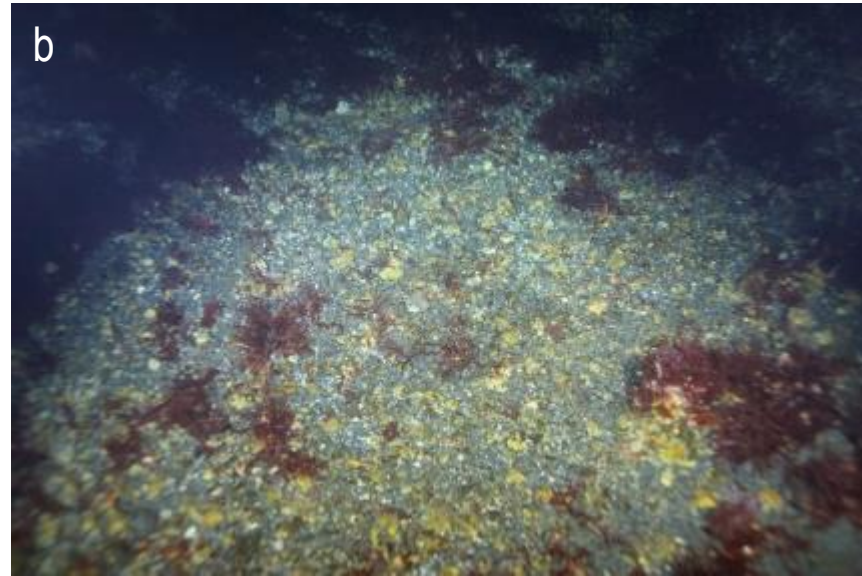
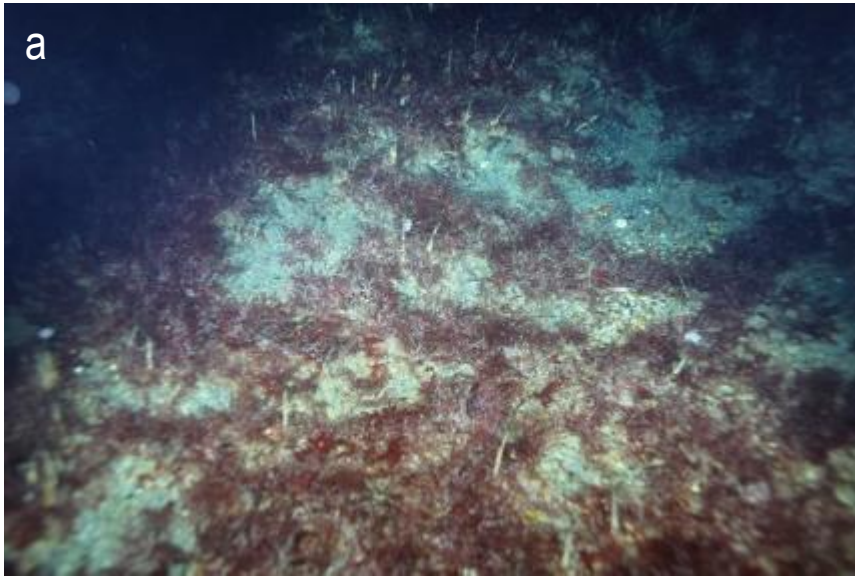
Ecoregion	Ecosystem type and Area (km ²)	Bathome	Ecosystem Description	Species
PEI sub-Antarctic	Least Exposed Mixed Shore 0.15 km ²	N/A	Protected eastern shores of Marion island comprising mixed substrate types across high and low profile rocky shores with sections of boulders, and including the only major sandy beaches on the island.	Algae: <i>Porphyra</i> sp., <i>Enteromorpha bulbosa</i> , <i>Durvillea antarctica</i> , <i>Rhodymenia</i> sp, <i>Lithothamnium</i> , <i>Rama Antarctica</i> , <i>Schizoseris</i> sp. Intertidal invertebrates: <i>Kerguelenella lateralis</i> , <i>Kidderia bicolor</i> . <i>Spirorbinae</i> , <i>Nacella delesserti</i> <i>Lasaea consanguinea</i> , Amphipoda (e.g. <i>Hyale grandicornis</i>) Giant kelp, <i>Macrocystis pyrifera</i> abundant in the nearshore Top predator rookeries: King penguin (<i>Aptenodytes patagonicus</i>), rockhopper penguin (<i>Eudyptes chrysocome</i>), southern elephant seals (<i>Mirounga leonine</i>), one high-density Antarctic fur seal rookery (<i>Arctocephalus gazella</i>)
PEI sub-Antarctic	Least Exposed Cliff and Broken Shore 0.16 km ²	N/A	Protected eastern shore of Prince Edward Island including steep cliffs with broken rock fringes at their base interspersed with high relief rocky shores	Intertidal assemblage consistent with Marion Island Least Exposed Mixed shores Giant kelp, <i>Macrocystis pyrifera</i> abundant in the nearshore
PEI sub-Antarctic	PEI sub-Antarctic Exposed Cliff and Broken Shore 0.33 km ²	N/A	Obliquely exposed south-eastern shores of both islands, comprising cliffs with fringes of broken rock and some high relief rocky shores	Intertidal rarely sampled but dominated by macroalgae and broadly typical invertebrate fauna Giant kelp, <i>Macrocystis pyrifera</i> common to abundant in the nearshore Marion Island characterised by two high-density Antarctic fur seal rookeries (<i>Arctocephalus gazella</i>). Other populations of top predators include King, Macaroni and Rockhopper penguins; Southern Elephant seals
PEI sub-Antarctic	PEI sub-Antarctic Highly Exposed Cliff and Broken Shore 1.68 km ²	N/A	Directly exposed western and north-western shores of both islands characterised by highly exposed sheer cliffs with lesser fringing by broken rock.	Intertidal rarely sampled but remains dominated by algae. Likely to support fewer mobile invertebrates such as gastropods and limpets Limited populations of giant kelp <i>Macrocystis pyrifera</i> in the nearshore but increasing to NW Western shores support multiple high-density Subantarctic fur seal (<i>Arctocephalus tropicalis</i>) rookeries. North-western shores are used by Antarctic fur seals (<i>A. gazella</i>), Macaroni (<i>Eudyptes chrysolophus</i>) King (<i>Aptenodytes patagonicus</i>) and Rockhopper penguins (<i>Eudyptes chrysocome</i>), and southern elephant seals (<i>Mirounga leonine</i>)
PEI sub-Antarctic	PEI sub-Antarctic Inner Shelf 162.94 km ²	Inner Shelf (0-90m)	Island associated, euphotic habitat within the sub-Antarctic ecoregion. Shallow subtidal zone of red algae in parts and Benthic habitat is flat or low relief soft substrate tending to mixed on the western and north western sides of the island	Red algae including <i>Schizoseris</i> . Giant kelp <i>Macrocystis pyrifera</i> in parts. Refugia for juvenile nototheniid fishes <i>Lepidonotothen larseni</i> and <i>Gobionotothen marionensis</i> Peak abundances of benthic taxa including the echinoidea, bryozoa, bivalvia and the crustacean <i>Nauticaris marionis</i> are typical

PEI sub-Antarctic	PEI Sub-Antarctic Outer Shelf 705.69 km ²	Outer Shelf (90-250m)	Island associated plateau region within the neritic zone. Predominantly soft substrata with discrete areas of mixed ground. It includes the shallow saddle-like feature between the islands and a small rocky feature called Natal Bank	Nototheniid fishes <i>Lepidonotothen larseni</i> , <i>L. squamifrons</i> . Peak abundances of benthic taxa including the echinoidea, bryozoa, Bivalvia. Important foraging habitat for many top predators including Antarctic fur seals, Sooty albatross (EN), Grey-headed albatross (EN), Indian yellow nosed albatross (EN), King penguins, White-chinned petrels (VU), Light mantled albatross, Macaroni penguins (VU), Wandering albatross (VU), Northern giant petrels and Orcas (DD)
PEI sub-Antarctic	PEI sub-Antarctic Shelf Edge 301.30 km ²	Shelf Edge (250-500m)	Seafloor habitat on the shelf edge of the island plateau within the PEI sub-Antarctic ecoregion. Soft and mixed substrate and increased gradient, particularly to the west of Marion Island and to the north of Prince Edward. The deepest island-associated ecosystem type and limit of neritic zone	Decline of previously abundant benthic invertebrate taxa but rapid increase in the Octocorallia and Bivalvia. Two records of VME taxa recorded here, both Pennatulacea
PEI sub-Antarctic	PEI sub-Antarctic Upper Slope 602.87 km ²	Upper Slope (500-1000m)	A narrow bathome following the contour of the island shelf edge but expanding to the east of the islands. Limited data suggests soft and mixed substrate	Continued increase in Octocorallia but overall decline in total epibenthic abundance 15 recorded instances of VME taxa, all Actinaria
PEI sub-Antarctic	PEI sub-Antarctic mid slope 1021.02 km ²	Mid Slope (1000-1800m)	Relatively narrow depth zone again following the contour of the island shelf but expanding to the east and north west of the islands. Unknown substrate type but likely soft and mixed based on presence of both soft and hard substratum dwelling taxa	Decline and stabilised diversity of Isopoda, Polychaeta, Gastropoda and Bivalvia 6 records of VME taxa including Scleractinia, Pennatulacea and Euryalida
PEI sub-Antarctic	PEI sub-Antarctic Lower Slope 85504.07 km ²	Lower Slope (1800-3500m)	Largest of the sub-Antarctic ecosystem types. Level or low relief seafloor dominating the central and eastern parts of the ecoregion. Uncertain substratum type but limited biotic data (VME records) suggests soft and mixed substrate including discrete rocky patches.	Bathome typified by a distinct mollusc assemblage and increasing isopod species richness 17 VME taxa records of Gorgonacea and Euryalida (basket and branching seastars). Important pelagic foraging areas for Sub-Antarctic fur seal, Orca, Southern rockhopper penguin (VU), Northern giant petrel, Wandering albatross (VU), Macaroni penguin (VU), Light mantled albatross, White chinned petrel (VU), King penguin (but only in the eastern section), Indian yellow-nosed Albatross (EN), Grey-headed Albatross (EN), Sooty albatross (EN), Antarctic fur seal.
PEI sub-Antarctic	PEI sub-Antarctic Abyss 55610.43 km ²	Abyss (> 3500m)	Large homogeneous level or gently sloping region, primarily soft substrate with limited evidence of mixed substratum inferred from biotic data. Extends along the southern boundary of the ecoregion	Two records of VME indicator taxa (Gorgonacea and Euryalida) One of the preferred foraging areas of Southern Elephant seals, sub-Antarctic fur seals, Southern rockhopper penguins (VU), Northern Giant petrels, Macaroni Penguins (VU), Light mantled albatross, King Penguins, Grey-headed Albatross (EN) and Sooty Albatross (EN). Wandering albatross (VU) forage to the south west and east

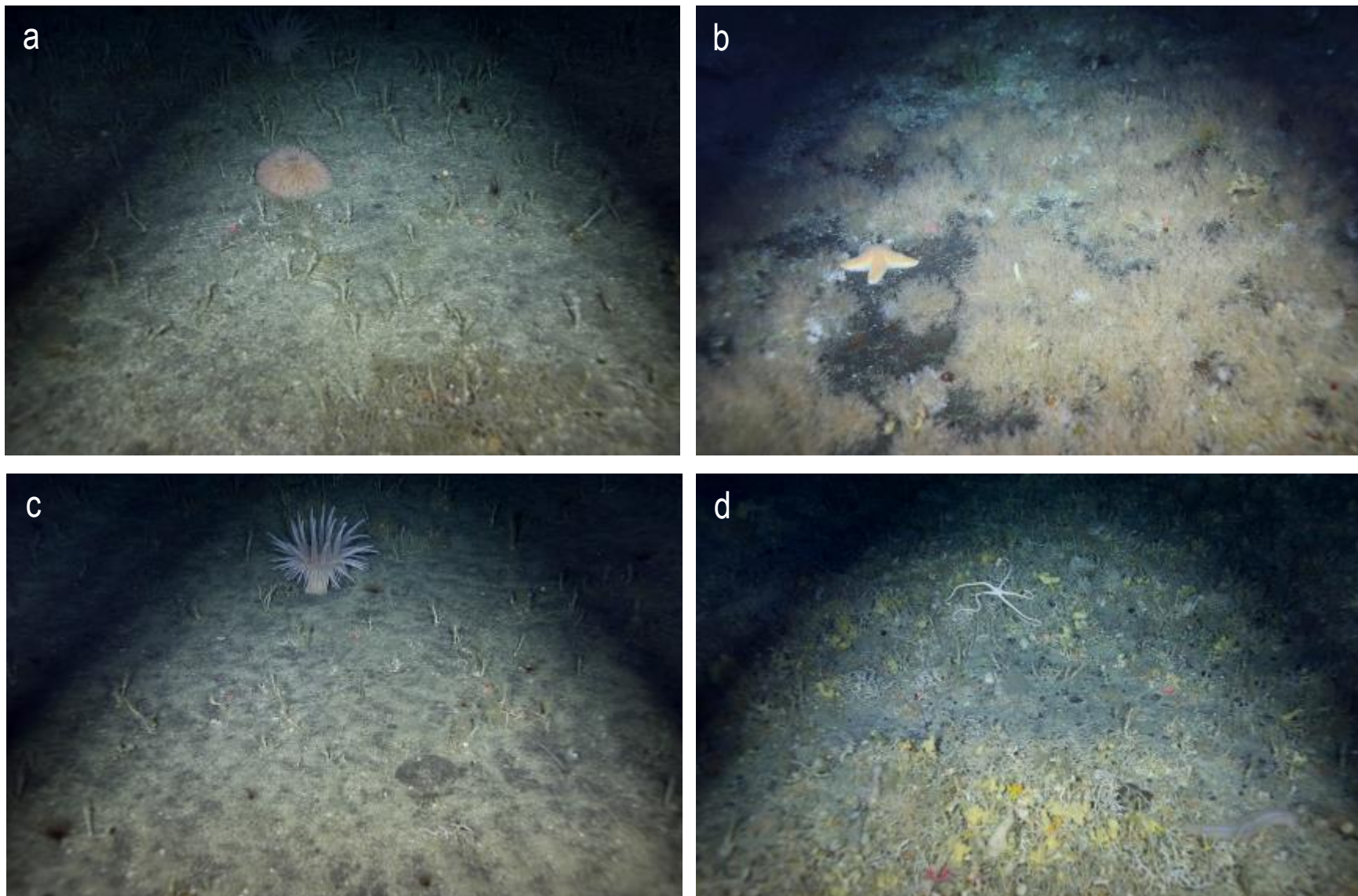
PEI sub-Antarctic	PEI sub-Antarctic Shallow Seamount 6950,01 km ²	Shallow (90-250m)	Four unique seamounts rise from the lower slope bathome (1800 – 3500 m) to less than 250 m from surface. Hard substrate provides distinct habitats from the large surrounding areas of deep homogeneous ecosystems	313 records of VME indicator taxa including Alcyonacea, Antipatharia, Euryalida, Actinaria, Stylasteridae, Anthoathecatae, Brachiopoda, Bryozoans, Scleractinia, Demospongiae, Pennatulacea, Ascidiacea Varied top predator foraging patterns, preferred by Sooty albatross (EN), Indian yellow nosed albatross (EN), King penguins, White chinned petrels, Light-mantled albatross, Wandering albatross (VU), Southern rockhopper penguins (VU) and Orcas (DD).
PEI sub-Antarctic	PEI Sub-Antarctic Seamount 3948.78 km ²	Various depths (250-3500m)	Seven seamounts with summits deeper than 250 m from surface. Typically hard substrate and mostly associated with the SWIR.	77 records of VME indicator taxa including Actinaria, Stylasteridae, Anthoathecatae, Bryozoa, Cnidaria, Gorgonacea, Scleractinia, Echinodermata, Antipatharia, Demospongiae, Demospongiae and Euryalida
PEI sub-Antarctic	PEI sub-Antarctic Shallow Spreading ridge 272,26 km ²	Shallow (250-500m)	Three small and isolated peaks on the SWIR, comprised of hard substratum. These are the second shallowest peaks on the SWIR within the PEI EEZ.	50 records of VME indicator taxa including, Antipatharia Actinaria, Stylasteridae, AZN Anthoathecatae, Scleractinia, Demospongiae, Gorgonacea, Pennatulacea, Euryalida (basket and branching seastars), Porifera (unclassified), Zoantharia Forms part of the wider area of importance for foraging top predators
PEI sub-Antarctic	PEI sub-Antarctic Upper Spreading Ridge 873.67 km ²	Upper Slope (500-1000m)	Multiple (14) scattered, isolated peaks of hard substrate on the ridges of the SWIR. These are the third shallowest (most elevated) peaks on the SWIR within the PEI EEZ	74 records of VME indicator taxa, including Alcyonacea, Antipatharia, Actinaria, Stylasteridae, Bryozoans, Cnidaria, Scleractinia, Demospongiae, Gorgonacea, Hexactinellida, Euryalida, Porifera, Ascidiacea and Zoantharia Forms part of the wider area of importance for foraging top predators
PEI sub-Antarctic	PEI sub-Antarctic Mid Spreading Ridge 14852,38 km ²	Mid Slope (1000-1800m)	Hard slopes of increasing gradient as part of the spreading ridge feature (SWIR). Forms the summit or shallowest areas of significant portions of the ridge.	High number (347) of VME indicator taxa records, including Alcyonacea, Antipatharia, Stylasteridae, Anthoathecatae, Bryozoans, Cnidaria, Scleractinia, Stalked crinoids, Demospongiae, Hexactinellida, Pennatulacea, Euryalida and Zoantharia. Southern elephant seals, sub-Antarctic fur seals, Orcas (DD), Northern giant petrels, Wandering Albatross (VU), White chinned petrels (VU), King penguins, Indian yellow nosed albatross (EN), Sooty albatross (EN) and Antarctic fur seals all forage on this habitat type
PEI sub-Antarctic	PEI sub-Antarctic Lower Spreading Ridge 56942.94 km ²	Lower Slope (1800-3500m)	Largest and deepest part of the SWIR slope. Extends in an almost contiguous swath across the PEI sub-Antarctic ecoregion. Hard substrate present. It is unlikely that this is the only ecosystem of its' type as the SWIR extends to the north-east and south-west of the PEI EEZ.	4 records of VME indicator taxa but species not recorded Important habitat for the foraging of Indian-yellow nosed Albatross (EN). Other species that do forage here include King Penguins, White chinned petrels (VU), Light mantled albatross, Wandering albatross (VU), Northern Giant petrels (which feeds primarily within the PEI sub-Antarctic ecoregion), Southern rockhopper penguins (VU), Orcas (DD), sub-Antarctic fur seals, Southern Elephant seals.
PEI sub-Antarctic	PEI sub-Antarctic Lower Rift Valleys and Troughs 2830.30 km ²	Lower Slope (1800-3500m)	Long narrow, closed, valleys and depressions within the surrounding lower slope spreading ridge. Soft substrate	Gorgonacea and Euryalida (basket and branching seastars) are some of the VME taxa found here

PEI sub-Antarctic	PEI sub-Antarctic Deep Rift Valleys and Troughs 12821.61 km ²	Abyss (> 3500m)	Two extensive elongate rift valleys bisect the western end of the SWIR within the PEI EEZ. They represent the deepest ecosystem type within the broader spreading ridge feature. Soft substrate dominate.	This is an important foraging habitat of Macaroni penguins (VU), Wandering albatross (VU), Northern Giant petrels, sub-Antarctic fur seals and Southern Elephant seals.
PEI sub-Antarctic	PEI sub-Antarctic Shallow Plateau 1804.84 km ²	Shallow (90-500m)	This shallow plateau feature is known as Galieni bank. This is the only feature of its kind in the PEI EEZ and there is a high likelihood of it only being found in the PEI sub-Antarctic region.	54 records of VME indicator taxa, including Antipatharia, Actinaria, Anthoathecatae, Bryozoans, Scleractinia, Stalked crinoids, Demospongiae, Gorgonacea, Hexactinellida, Euryalida, Porifera, Ascidiacea, Serpulidae and Zoantharia. Sub-Antarctic fur seal, Orca (DD), Southern-rockhopper Penguin (VU), Northern-giant petrel, White-chinned petrel (VU), King Penguin, Grey headed albatross (EN), Sooty albatross (EN) and Antarctic fur seals all forage within this ecosystem type.
PEI sub-Antarctic	PEI sub-Antarctic Mid Plateau 15247.83 km ²	Mid Slope (1000-1800m)	Part of larger plateau feature. Rising soft and mixed substrate, sometimes flattening out within the mid slope bathome or continuing shallower.	313 records of VME indicator taxa including, Antipatharia, Actinaria, Anthoathecatae, Bryozoans, Scleractinia, Stalked crinoids, Demospongiae, Gorgonacea, Hexactinellida, Euryalida, Porifera, Ascidiacea, Serpulidae and Zoantharia. One of the most preferred foraging habitats of Antarctic fur seals, Sooty albatross (EN), Grey-headed Albatross (EN), Indian yellow-nosed Albatross (EN), King penguins, White Chinned petrels (VU), Macaroni penguin(VU), Wandering Albatross (VU), Northern giant petrels, Southern-rockhopper penguins (VU), Orcas (DD) and sub-Antarctic fur seals
PEI sub-Antarctic	PEI sub-Antarctic Lower Plateau 36622.33 km ²	Lower Slope (1800-3500m)	Most extensive part of the large eastern plateau within the Sub-Antarctic ecoregion. Gently sloping soft and mixed substrate rising from surrounding deep ocean floor. It is unlikely that this slope feature is only found in the PEI EEZ	20 records of VME indicator taxa including Gorgonacea, Stylasteridae, Euryalida (basket and branching seastars), Antipatharia, Bryozoans, Ascidiacea, unclassified Echinodermata and Demospongiae. Important foraging habitat for Antarctic fur seals, Sooty Albatross (EN), Grey-headed Albatross (EN), White-chinned petrels (VU), Macaroni penguins (VU), Wandering Albatross (VU), Northern giant petrels, Southern rockhopper penguins (VU), Orcas (DD) and sub-Antarctic fur seals.
PEI Temperate	PEI Temperate Seamount 83.71 km ²	Various depths – (250-3500m)	A small seamount ecosystem comprising hard substrate, which occurs within the PEI Temperate region	Part of the wider foraging habitat of Sooty Albatross (EN), Indian yellow-nosed albatross (EN), White chinned Petrels (VU), Wandering Albatross (VU) and Orcas (DD)
PEI Temperate	PEI Temperate Mid Slope 270.43 km ²	Mid Slope (1000-1800m)	A small, isolated, feature of soft substrate rising from the surrounding lower slope habitat. It forms the lesser of only two elevated features in the Temperate ecoregion.	Part of the wider foraging habitat of Sooty Albatross (EN), Indian yellow-nosed albatross (EN), White chinned Petrels (VU), Wandering Albatross (VU) and Orcas (DD)
PEI Temperate	PEI Temperate Lower Slope 10371.34 km ²	Lower Slope (1800-3500m)	Soft sediment plain and gently sloping seafloor. It is the largest ecosystem type within the Temperate ecoregion, covering the entire northern and eastern sectors	Foraging by Sooty Albatross (EN), Indian yellow-nosed albatross (EN), White chinned Petrels (VU), Wandering Albatross (VU) and Orcas (DD) all forage here.

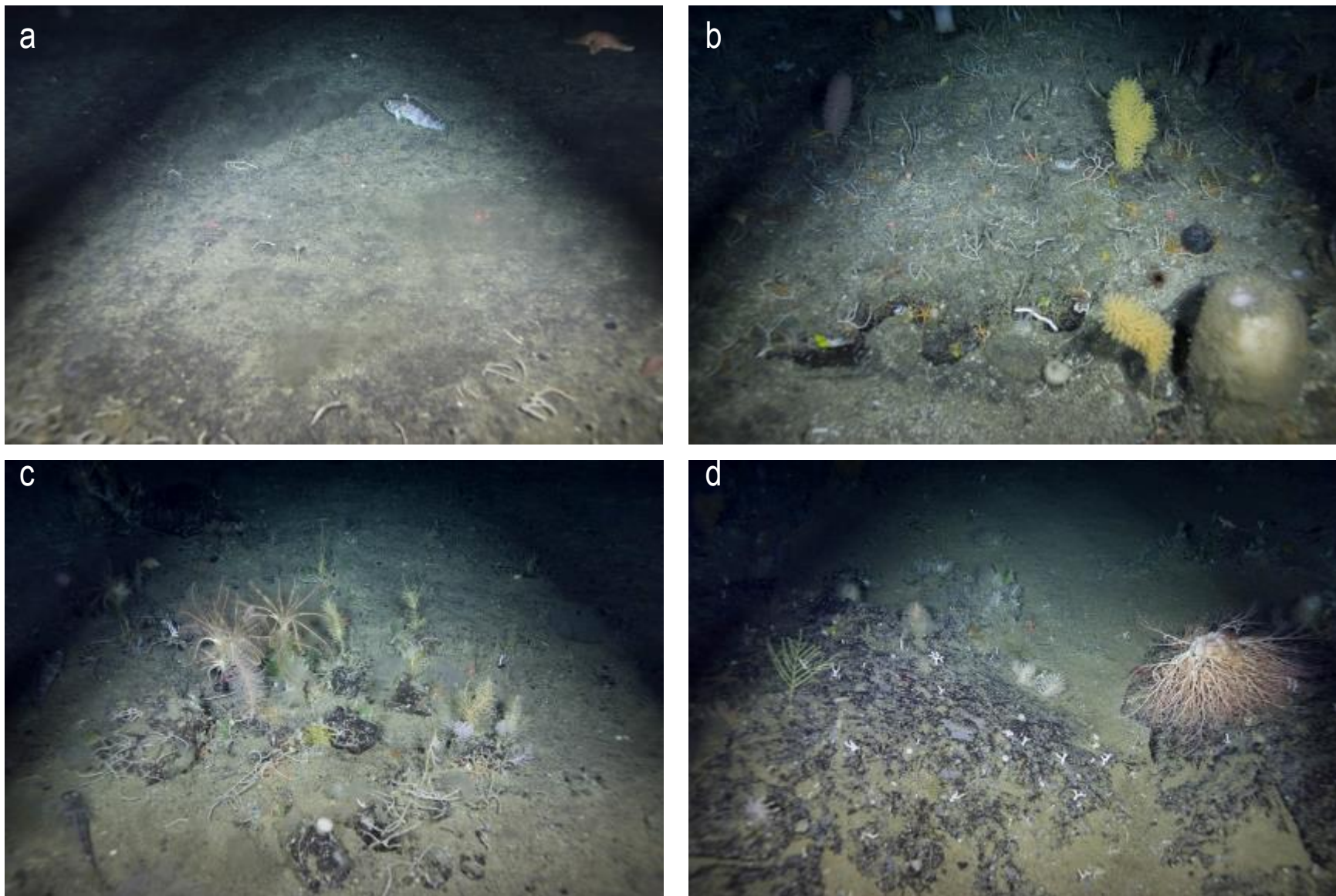
PEI Temperate	PEI Temperate Abyss 5843.21 km ²	Abyss (> 3500m)	Soft sediment abyssal plain, encompasses the western half the Temperate ecoregion. It is the second largest ecosystem in this ecoregion	Foraging by Sooty Albatross (EN), Indian yellow-nosed albatross (EN), White chinned Petrels (VU) and Wandering Albatross (VU).
PEI Polar Front	Prince Edward Island Polar Front Seamount 1760.03 km ²	Various depths (250-3500m)	Two isolated seamounts composed of hard substrate. They rise from abyssal depths of more than 3500 m and providing the only other ecosystem type within the PEI Polar Front ecoregion.	No VME indicator taxa yet recorded from these features.
PEI Polar Front	Prince Edward Island Polar Front Abyss 155422.06 km ²	Abyss (> 3500m)	Deep plains of soft substrate. Pelagic environment strongly influenced by the productive Polar Frontal Zone. Forms the largest contiguous area of abyssal habitat in the PEI EEZ. As part of the much larger Atlantic Basin, it is not unique to the EEZ.	Important foraging area for Antarctic Fur seals, sooty albatross (EN), Grey-headed Albatross (EN), King Penguin, Light-mantled albatross, Wandering Albatross (VU), Macaroni Penguin (VU), Southern-rockhopper penguin (VU), Northern giant petrel and Southern Elephant seal
PEI Polar Front	Ob and Lena Polar Front Abyss 4071.87 km ²	Abyss (> 3500m)	The most southerly ecosystem type. Soft abyssal plain forming a peripheral part of the major Ob and Lena seamount complex to the east of the PEI EEZ	Of lesser importance for top predators, but with some foraging by Southern rockhopper penguins (VU), Macaroni penguins (VU), King penguins, Light-mantled albatross and Antarctic fur seals



Appendix E. Photographic examples of the Inner Shelf ecosystem type within the 0 – 90 m bathome. These show the typical benthic communities observed off the (a) northern (77m), (b) western (80m), (c) southern (70m) shores of Marion Island; while (d) shows the typical benthic habitat within the deep kelp (*M. pyrifera*) forests on Natal Bank in the inter-island region (63m).



Appendix F. Photographic examples of seafloor communities defining the Outer Shelf ecosystem type defined by the 90 – 250m bathome. Panels show benthic communities from the (a) central or 'inter-island' outer shelf (182m), (b) eastern outer shelf (118m), (c) western outer shelf and, (d) the northern outer shelf (225m), the nearest to Prince Edward Island of all the images.



Appendix G. Example photographs of benthic communities of the Shelf Edge ecosystem type that occurs within the 250 - 500 m bathymetry. Panels show the seafloor habitat of the (a) shelf edge west of the islands (402m), (b) the central 'inter-island' shelf edge (315m), meanwhile panels (c) and (d) represent the south-eastern shelf edge (369m)

Appendix H. taken directly from Blackburn *et al.* (2011). Adapted from Greve *et al.* (2017) Table 2-A1.

Status code	Meaning of invasion status from Blackburn <i>et al.</i> (2011)
A	'Not transported beyond limits of native range'
B1	'Individuals transported beyond limits of native range, and in captivity or quarantine (i.e. individuals provided with conditions suitable for them, but explicit measures of containment are in place)'
B2	'Individuals transported beyond limits of native range, and in cultivation (i.e. individuals provided with conditions suitable for them but explicit measures to prevent dispersal are limited at best)'
B3	'Individuals transported beyond limits of native range, and directly released into novel environment'
C0	'Individuals released into the wild (i.e. outside of captivity or cultivation) in location where introduced, but incapable of surviving for a significant period'
C1	'Individuals surviving in the wild (i.e. outside of captivity or cultivation) in location where introduced, no reproduction'
C2	'Individuals surviving in the wild in location where introduced, reproduction occurring, but population not self-sustaining'
C3	'Individuals surviving in the wild in location where introduced, reproduction occurring, and population self-sustaining'
D1	'Self-sustaining population in the wild, with individuals surviving a significant distance from the original point of introduction'
D2	'Self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from the original point of introduction'
E	'Fully invasive species, with individuals dispersing, surviving and reproducing at multiple sites across a greater or lesser spectrum of habitats and extent of occurrence'