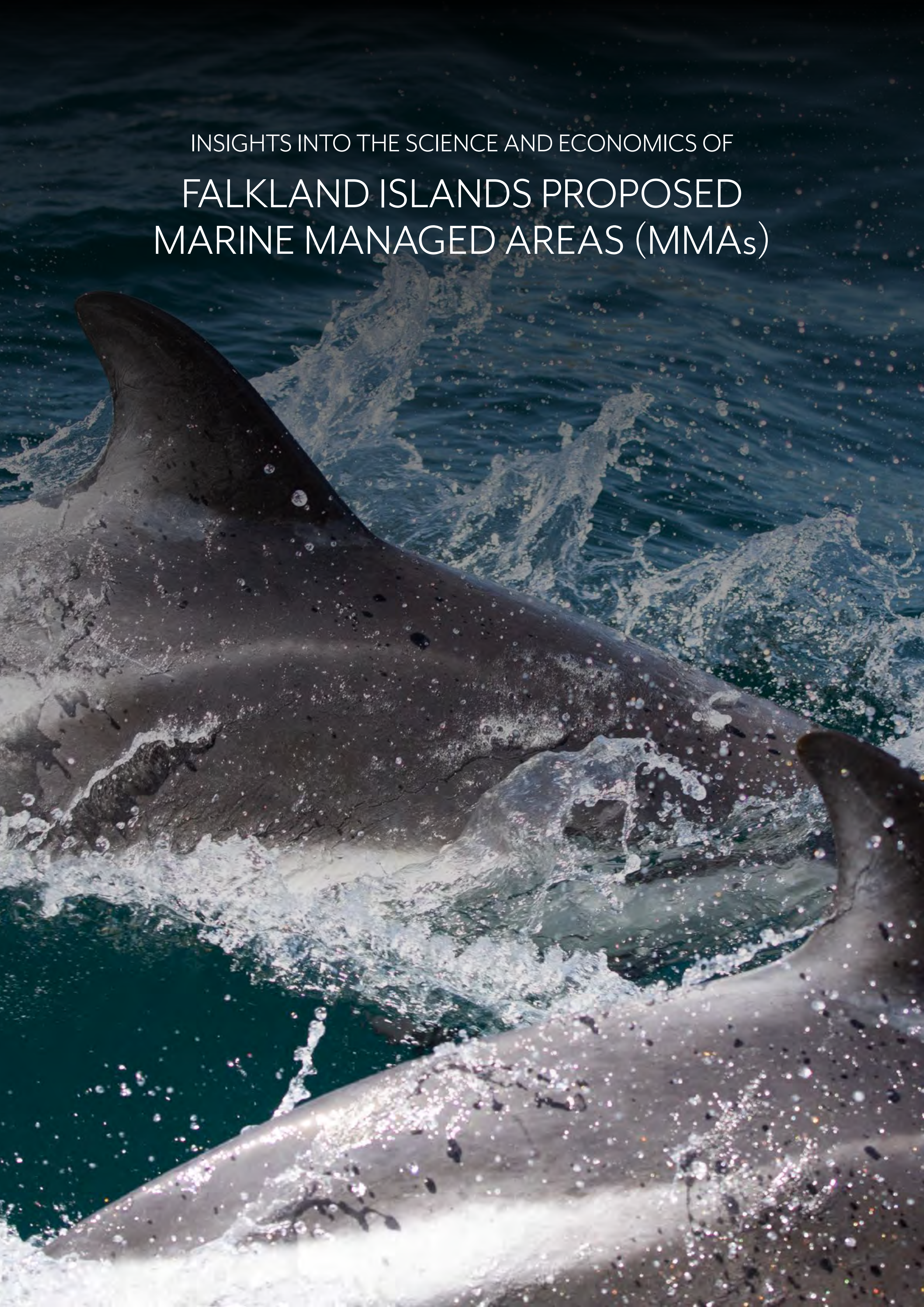

INSIGHTS INTO THE SCIENCE AND ECONOMICS OF

FALKLAND ISLANDS PROPOSED MARINE MANAGED AREAS (MMAs)

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INTRODUCTION CONTENTS

1. OVERVIEW OF THE FALKLAND ISLANDS MARINE MANAGED AREAS PROCESS

The Falkland Islands are positioned as a unique geophysical gateway between the southern tip of South America, the sub-Antarctic and Antarctica. The Falklands Interim Conservation and Management Zone (FICZ; established in 1986) and the Falklands Outer Conservation Zone (FOCZ; established in 1990) extending to 200 nautical miles (~370kms), gave the Falkland Islands sovereignty over its fisheries and marine environment (Harte and Barton, 2007). Commercial fisheries are now the economic pillar of the Falkland Islands, accounting for most of the Gross Domestic Product (GDP) (up to 59% in 2007 and 2016), with local and international tourism being the second greatest contributor to GDP (Falkland Island Tourist Board, 2018, Bormpoudakis et al., 2019, Smith, 2019). By necessity, the Falkland Islands approach to marine spatial planning (MSP) differs from other UK Overseas Territories, such as Ascension Island, Saint Helena and Tristan da Cunha, which are listed as part of the broader United Kingdom Governments 'Blue Belt' program. The Falkland Islands are not part of the Blue Belt program and the relative independence and economic wealth of the Falkland Islands presents unique challenges for conservation planning. Hence, a fundamental consideration while developing the initial phases of the MSP process has been to respect culturally and economically important activities, whilst at the same time working to protect the marine environment (Fig. 1).

To balance the need for regional economic security and biodiversity conservation, an holistic approach to MSP was initiated in 2014 and led by the South Atlantic Environmental Research Institute (SAERI). The overarching aim of the MSP project was to collate data to understand how humans and marine-life use the Falkland Islands marine environment (Table 1). Following the successful completion of the MSP project in February 2016, there was a desire to maintain the momentum this project generated, and utilise some of the tools and datasets developed. This led to the commencement of Phase II of the MSP project, which included the Assessment of Fishing Closure Areas as Sites for wider management or AFCAS project (Golding 2017, Brickle et al. 2019).

The AFCAS project commenced in 2016, with SAERI being directed by the Falkland Islands Government (FIG) to undertake the work, on behalf of the Department of Natural Resources. The AFCAS study assessed current fishing closure areas against international protected area criteria, and demonstrated that with some changes, including identifying and stating nature conservation objectives, FIG could use pre-existing permanent and temporary fishery closures as sites for wider marine management, whilst also meeting (at the time) its international protected area Aichi Targets under the Convention of Biological Diversity (CBD). The AFCAS findings were documented in a report and the areas were considered to be globally important for conservation (Golding 2017). The AFCAS areas included marine wilderness areas that have little or no fishing impact, have irreplaceable biodiversity and are ecologically representative, but presently do not have a legal framework for protection (Golding 2017, Brickle et al. 2019). The AFCAS report outlined potential Marine Managed Areas (MMAs) that could be developed from existing fishing closures, as well as ideas on how these could be managed into the future. The findings from AFCAS were subject to a public consultation process, which commenced on 15th March 2017. Following the end of the consultation process on 5th May 2017, there was a desire to feedback the key messages from the consultation to the MSP Stakeholder Group, ahead of the consultation report being published. To aid this, a second stakeholder workshop was organized on the 8th June 2017. The AFCAS stakeholder workshops concluded that further evidence was needed to support the proposed MMAs.

Specifically, the AFCAS study prioritized seven marine wilderness areas as potential MMAs (Brickle et al. 2019). These are the Burdwood Bank, which includes two potential MMAs (Fig. 2), selected because of benthic biodiversity and importance as foraging habitat for migratory species (Augé et al. 2018); MMAs around the Jason Islands Group, (recognized as a terrestrial KBA), Bird Island, Kidney and Cochon Island and Beauchene Island, selected as seaward extensions of globally important breeding colonies of seabirds and pinnipeds where animals are known to congregate (e.g., Granadeiro et al. 2018) (Fig. 2); and an inshore MMA around the Falkland Island coastline, which is near pristine owing to fishing restrictions within three nautical miles of the Falkland Islands coastal baseline since 1986 (Fig. 2).

Phase 3 of the Marine Spatial Planning project started in 2018 and was a Darwin Initiative funded project 'Fine-scaling the design of Falkland Islands Marine Managed Areas'. Phase 3 focused on collecting and collating biological and analyzing economic data to provide further evidence for FIG and stakeholders to understand how the proposed MMAs could impact current and future activities and what biodiversity they preserve.

2. DOCUMENT OVERVIEW AND PURPOSE

This document serves to highlight key information collected by SAERI since 2014, and especially as part of the recent Darwin Plus Marine Managed Areas (MMA) project, to support FIG in its consideration of sites proposed as Marine Managed Areas (MMAs). The information indicates the importance of these inshore and offshore areas for the Islands. It also provides new insights on the functioning of the marine ecology of the Falkland Islands which will help to inform management and protection of these areas, but also of the broader marine environment.

The Falkland Islands hosts diverse and ecologically important inshore ecosystems, offshore areas of high biodiversity, and globally important populations of marine higher predators, intertwined with important biological connections to Southern Ocean and Patagonian ecosystems. In nearshore waters, pristine kelp forests, which are recognised as structurally complex habitats, provide important ecosystem services, including blue carbon stores and nurseries for commercially important species of fish and squid (Van Tussenbroek, 1993; Friedlander et al., 2020). In deeper waters, the eastern slope of the Burdwood Bank is recognised as an important Vulnerable Marine Ecosystem (VME), with unique and fragile seafloor species and habitats (Auster et al., 2011; Brewin et al., 2020) and together, these areas serve as regions of enhanced biological productivity that support numerous seabird, seal and cetacean species (Baylis et al. 2021). In addition to supporting globally important biodiversity, our oceans support marine industries that are central to the Islands' economy. Recognising the need for a holistic marine management approach across all sectors that promotes sustainable use of the Falkland Islands' marine resources and that safeguards its biodiversity, a long-term process of marine spatial planning (MSP) began in 2014 with the 'Marine Spatial Planning in the Falkland Islands' Darwin Plus project (DPLUS027) (Augé 2015, 2016a). Following the successful conclusion of DPLUS027 a second phase (MSP Phase II) covered, among other things, the AFCAS sites for wider marine management as potential MMAs, using criteria for Marine Protected Areas to help guide the areas selected (Table 1). Several MMAs, as identified in this document, are now being considered by the Falkland Islands Government (ExCo 46/21). It is important to note that research, data collection, data analyses and reporting on the dynamics of these areas are still ongoing and will be reported, as they are completed. Large amounts of data have been collected and remain the focus of research for a number of international and Falkland Islands organizations. The purpose of this document is to provide an overview of key data to date collected as part of the ongoing technical work by SAERI to support the proposed MMAs.

Specifically:

CHAPTER 1: INSHORE MARINE MANAGED AREAS

Chapter 1 focuses on the Falkland Islands nearshore environment and the proposed inshore MMA. This proposed MMA comprises all of Falkland Islands internal waters as measured from 3 nm from the baseline inwards to the intertidal highwater mark. This area was identified as important as it is highly productive, pristine, highly diverse and key to the function of the shelf ecosystem. What is immediately noticeable about nearshore and coastal Falkland Islands waters is the abundance of wildlife and very dense kelp beds. What is not noticeable from the surface is the very high biological diversity in the flora and fauna. Kelp blankets the islands and is a key species in the function of this inshore system and it is becoming increasingly clear that it is key to the function of the Falkland Islands shelf system too. Work by SAERI and SMSG (published in Bayley et al. 2021) highlighted the importance of giant kelp (*Macrocystis pyrifera*) in terms of ecosystem services and the potential for blue carbon storage (Chapter 1.1). Kelp provides many services to the Falkland Islands and international community. This includes mitigating storm damage, nutrient cycling and providing habitat and productivity to many harvestable resources indirectly through 'trophic bridges' or directly as nurseries or habitat at differing life history stages for many species. What remains unknown is the role of kelp forests in sequestering CO2 and therefore aiding climate regulation. This has been overlooked in assessments of the beneficial services they provide. It is thought that the *Lessonia* group of species in the Falkland Islands have a greater bathymetric and spatial distribution and thus a greater biomass than *Macrocystis pyrifera*.

The Chapter also explores the reasons for Falkland Islands high inshore biological biodiversity (Chapter 1.2). During the last glacial maximum (LGM / ice age), distributions of taxa were known to retreat to refugia for recolonization. The Falkland Islands have been shown to be one such refugium, being free from ice during the LGM, with species rapidly re-dispersing to Patagonia and the surrounding sub-Antarctic from the Falklands' 'founder' populations after the ice retreated. This led to high species diversity with high genetic diversity at population levels and is a key feature of ongoing research.

Chapter 1 provides the first insights into intertidal spatial community dynamics, and examines subtidal community structure around the Kidney Island National Nature Reserve in bathymetric and temporal scales.

The marine environment that surrounds the Falkland Islands is still an area of scientific discovery. With a huge coastline and small population, research has been generally *ad hoc* and opportunistic in nature. This research is now more systematic and testament to this are new discoveries including new previously unknown habitats, species and ecological patterns being described. Since 2010 a good deal of new species have been described including sponges, polychaetes and algae. This taxonomic work continues with new species of fish, opisthobranch molluscs and crustaceans being described. Inshore research also continues to be a key priority in SMSG, SAERI and with their international partners. In collaboration with SMSG there is now the opportunity to move into much deeper water, from SCUBA depths (<=20 m) with the use of side-scan sonar, Remotely Operated Vehicles (ROVs), drop down cameras, small Agassiz trawls and plankton nets.

Image: *Munida subrugosa*. Credit: SMSG.

CHAPTER 2: OFFSHORE MARINE MANAGED AREAS (BURDWOOD BANK)

Chapter 2 focuses on the offshore environments of the Falkland Islands. The deep sea is considered the great unknown region of our planet and biodiversity estimates are lacking as most deep-sea ecosystems have only recently been discovered. On the seafloor, some of these environments are defined as VMEs as they are considered isolated areas of high biodiversity and productivity. In deep Falklands waters, one of the proposed MMAs encompasses the eastern Burdwood Bank. We review the unique and fragile seafloor taxa (e.g. corals and other delicate sessile animals), known as VME indicator taxa, and their habitats. The proposed Burdwood Bank National Marine Nature Reserve (NMNR) and Sustainable Multi-use Zone (SMZ) will help to ensure the long-term resilience of shelf and slope habitats and dependent species, as well as the sustainability of economically important fisheries by protecting connectivity between neighboring biodiversity refugia. There is also an emerging basis for blue carbon research in the Falkland Islands. Blue carbon is broadly defined as the CO2 absorbed from the atmosphere by marine ecosystems, which is ultimately sequestered for 100s to 1000s of years. We undertake and present preliminary research, which suggests that the Burdwood Bank hosts high carbon sequestration potential. Newly identified carbon rich biodiversity habitats including abundant stylasterid (lace) and scleractinian (cup) coral assemblages add to the conservation significance of this region. Such communities are hypothesized to be particularly vulnerable to the effects of physical disturbance, exemplifying their designation as VME indicator taxa. A focus on maintaining ecosystem function at the site of sequestration, where it is most crucial to long-term climate mitigation, includes conservation of VME taxa (such as corals) and the ecosystem services a biodiverse seafloor habitat can provide. The high biological diversity on the Burwood Bank compared to other parts of the Falkland Islands and High Seas area to the north of the FOCZ with regards to fish and squid is also presented. This work illustrates the different community structure on the shelves and slopes of the Falklands Islands and High Seas areas, with the Burdwood Bank showing greater dissimilarity. Some of the reasons for this include the habitat complexity of the seamount / ridge characterized by Bank's the unique geomorphology, bathymetry and indeed hydrodynamic complexity of the Burdwood Bank. And, importantly, also the Burdwood proximity to the Antarctic Circumpolar Current (ACC) resulting in a meeting of sub-Antarctic and Magellanic fauna.

CHAPTER 3: MARINE HIGHER PREDATORS

The Falkland Islands are home to globally significant populations of seabirds, seals and cetaceans. Chapter 3 delves into our charismatic upper trophic level marine predators (seabirds, seals, and cetaceans). It is widely recognised that the marine areas surrounding seabird and seal breeding colonies are important – presumably one motivation for the no-take zone within 3 nm of the Falkland Islands baseline, which was established in 1986 as a fisheries license condition. However, how seabirds and seals use our marine waters, and how they overlap with proposed MMAs remains poorly understood. To address this knowledge gap, all available tracking data were collated from prior studies. We assessed how the proposed Falkland Islands MMA network overlaps with the distribution of seabirds and seals. The reader should be aware that we focused on (i) species that breed in the Falkland Islands, (ii) that we focused on the non-migratory movements of animals, and (iii) that tracking data was not available for all seabird and seal species (although the tracking data collated should be considered as broadly representative of seabirds and seals that breed in the Falkland Islands).

The proposed inshore MMA, which extends 3 nautical miles from the Falkland Islands baseline, overlapped extensively with areas used by seabirds and seals. This reflects breeding colonies being distributed around much of the Falklands coastline, and animals spending time near breeding colonies. We also identified potential IUCN Key Biodiversity Areas (p KBAs) - sites that *"contribute significantly to the persistence of global biodiversity"*. We identified pKBAs, because we wanted to place the conservation value of the proposed MMAs into a global context for marine predators, and identify other important candidate areas for marine protection using standardised criteria. Our intention was not to designate KBAs for seabirds and seals, but rather to understand how pKBAs overlapped with MMAs. Up to 45% of the pKBAs identified were located within the proposed MMAs. In particular, the proposed Jason Islands MMA overlapped with pKBAs for 3 species, suggesting it is a KBA hotspot. However, we also found that everywhere is likely to be a KBA (72 % of the Falkland Islands Conservation Zone). We also collated survey data for Peale's dolphins, Commerson's dolphins and sei whales. Although we compiled the most recent cetacean survey data, it should be noted that aerial and boat-based surveys were typically undertaken within the boundaries of the proposed Falkland Islands MMAs and therefore the majority of cetacean sightings were within the proposed MMAs. Hence, our aim was to provide a brief overview of the cetacean data available, rather than undertake an exhaustive analysis. The cetacean surveys further highlight the importance of Falkland Islands nearshore waters, and the proposed inshore MMA in particular.

Given the limited survey data outside of the proposed MMAs, predictive models are a useful tool to explore potential distributions over larger areas. The predictive models for sei whales and Commerson's dolphins revealed 'hotspots' of predicted occurrence – areas where high numbers of cetaceans are more likely to be found. For both sei whales and Commerson's dolphins the majority of the 'hotspots', fall within the proposed inshore MMA, which again, highlights the importance of the inshore MMA to cetaceans. The proposed MMAs offer enhanced protection for the designated sei whale KBA (over 70 % of the sei whale KBA, and 99 % of confirmed sei whale sightings occurred within the proposed MMA boundaries).

However, research on seabirds, seals and cetaceans is ongoing. SAERI and other organizations continue to fill data gaps, and expand the breadth and depth of tracking data available and we continue to explore more robust statistical frameworks for the analysis of movement data. The overarching aim of this ongoing research is to enable better informed monitoring and management of the proposed MMAs, should they be designated. The proposed Falkland Islands MMAs are intended to be ecologically representative – this means they take into account all the different parts of our ecosystem (e.g., seafloor, plankton and zooplankton, kelp forests, fish, squid, seabirds, cetaceans), rather than being driven by a single species. Ultimately, the proposed MMAs benefit all marine higher predators that we studied, but in different ways.

CHAPTER 4: ECONOMIC IMPLICATIONS

Chapter 4 provides a review of the potential economic implications of the proposed MMAs. These reports were commissioned by SAERI in 2019, and several assumptions were made with regard to MMA zones and activities, to enable an economic review. Therefore, the relevance of the information contained in this report is likely to change, depending on the outcome of the stakeholder consultation process.

On the basis of MMA design assumptions (detailed in chapter 4), the proposed Burdwood Bank SMZ is the only MMA to overlap with the commercial fishing sector (Fig. 2). The current Burdwood Bank SMZ design, as evaluated, is compatible with sustainable fishing, such as the Marine Stewardship Certified Falkland Islands longline fishery. Hence, we do not anticipate impacts to current commercial fishing operations.

The NMNRs and the inshore SMZ are not expected to have significant economic impacts on offshore fishing activity. However, the small-scale artisanal mullet and snow crab fisheries as well as recreational fisheries would not be compatible with the Cochon, Kidney, Bird, Jasons and Beauchêne Islands NMNRs. Most of these activities take place around settlements, though, which tend to be away from these NMNRs, so any effect is likely to be negligible.

WHY ARE FISHERY CLOSURE AREAS UNSUITABLE AS MMAs IN THEIR CURRENT FORM?

Under Schedule 1(a)(ii) of the Fishing Regulations Order 1987 (Falkland Islands Government, 1987), fishing licenses shall not extend to within 3 nautical miles of the baseline, (the area represented by the proposed inshore MMA). However, fishing closure areas can be amended at the discretion of the Director of Natural Resources and are not gazetted in legislation. Therefore, they are not considered to have fixed, permanent spatial extents, nor do they not have stated nature conservation objectives. MMAs, if designated, have conservation at their heart and will be recognised through policy and legislation, and managed through robust management and monitoring plans.

WHAT ARE IUCN MPAs?

The International Union for the Conservation of Nature (IUCN) is a membership Union of over 1,400 government and non-government organisations. The IUCN developed a set of guidelines to define a protected area. If a site meets the IUCN definition of a protected area, it could qualify for one or more IUCN categories, which classify protected areas according to their management objectives. There are many benefits to applying IUCN protected area management categories (e.g., global framework, recognised by the Convention on Biological Diversity).

However, within island nations, there is a demonstrated need to balance socio-economic objectives, such as financial resilience, with environmental objectives. Island nations often have complex stakeholder landscapes and reaching consensus on protected areas requires careful and thoughtful planning and consultation. The IUCN periodically revise and change the criteria for MPA categories. This is largely in response to issues in the accuracy and consistency of how IUCN categories are assigned and reported when applied to marine areas. Shifting criteria for IUCN MPA categories could create uncertainty in protected area designation, because changes made to IUCN categories after designation may not be compatible with management plans, national legislation, national economic security, and complex stakeholder landscapes.

The rest of the inshore area around the Falkland Islands is an SMZ, which is compatible with these small-scale artisanal and recreational fisheries.

For the oil, gas and mineral sector, there is no overlap between current or currently proposed industrial activity (or license blocks) and MMAs. For tourism, the inshore SMZ is compatible with tourist and recreational activities. The NMNRs around Cochon, Kidney, Bird, and Jasons Islands Group would exclude mass tourism, though smaller visitor volumes would be compatible. The strict NMNR around Beauchêne Island would exclude future development of tourism, but none currently takes place.

The movement of yachts are unrestricted by the proposed MMAs. Jetty development and shipping activity (large commercial vessels) could potentially be limited/restricted in the Jason Islands Group, Bird Island, Beauchêne Island, Cochon and Kidney Islands NMNRs.

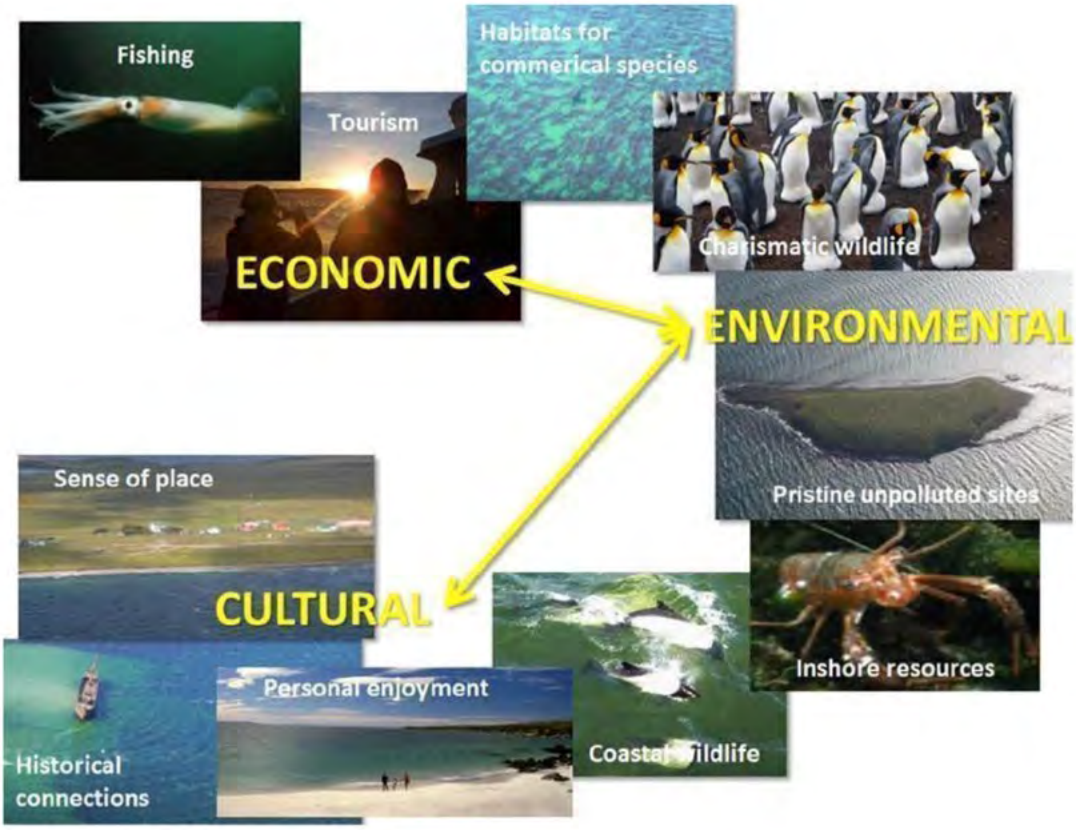

Fig 1: *The current main economic activities in the Falkland Islands are marine-based (commercial fishing and tourism). Economic activities entirely rely on a healthy marine environment where fish can reproduce and grow and where wildlife attracting the tourists can thrive. The marine environment is also important to islanders, with strong cultural links. Therefore, there is an intimate connection between managing the marine environment and ensuring the Falklands' economy is sustainable, while ensuring people can enjoy their favorite coastal places, long into the future. This figure represents these connections in the Falkland Islands.*

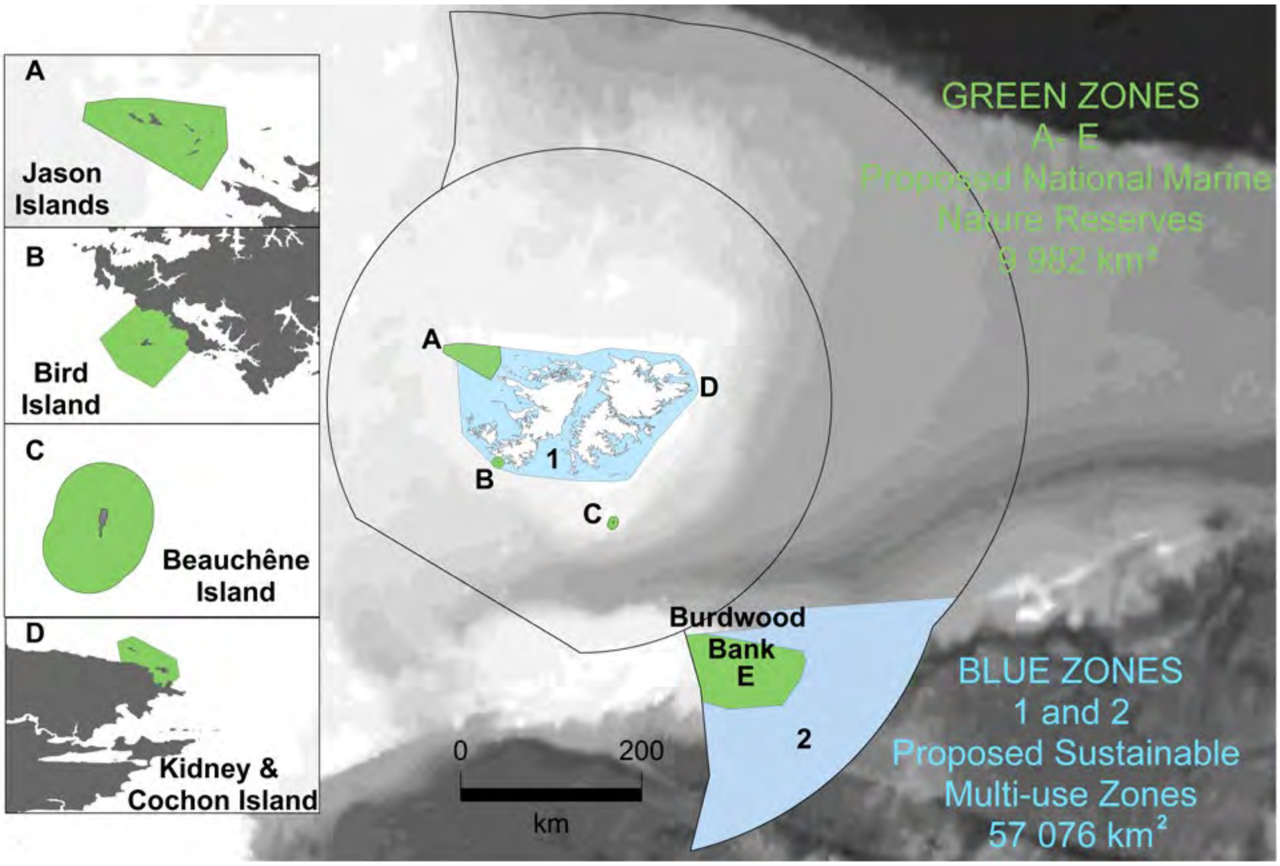

Fig 2: *Location of the proposed Marine Managed Areas. The green zones are proposed National Marine Nature Reserves (Jason Islands, Bird Island, Beauchene Island, Kidney and Cochon Island and Burdwood Bank). The Blue Zones are Sustainable Multi-use Zones (inner Falkland Islands waters and outer Burdwood Bank).*

Table 1: Overview of the three phases of Marine Spatial Planning in the Falkland Islands, which helped identify the proposed Marine Managed Areas.

Phase 1: Marine Spatial Planning (MSP) in the Falkland Islands	**Phase 2: Assessment of Fishing Closure Areas as Sites for wider management**	**Phase 3: Fine scaling the design of Falkland Islands Marine Managed Areas**
Funded by: Darwin Initiative & FIG	Funded by: FIG	Funded by: Darwin Initiative & FIG
2014-2016	2016-2017	2018-2021
Project lead: SAERI and FIG	Project lead: SAERI and FIG	Project lead: SAERI and FIG
Project reference: www.south-atlantic-research.org/research/completed-research-projects/marine-spatial-planning-for-the-falkland-islands/	Project reference: www.south-atlantic-research.org/research/completed-research-projects/marine-spatial-planning-phase-2/	Project reference: www.south-atlantic-research.org/research/marine-science/fine-scaling-the-design-of-falkland-islands-marine-management-areas/
To enable coordinated and sustainable management of the marine environment, and to identify areas for marine management and conservation, a Marine Spatial Planning (MSP) process was initiated in the Falkland Islands in 2014 (Augé, 2016b). The main aims of the MSP project were to establish the baseline information required to enable MSP. Essentially to understand how man and marine fauna and flora utilised the Falkland Islands seascape. This was done through a series of mapping and modelling exercises. The project achieved the following: It gathered and created spatial data to map how humans and wildlife use the marine environment around the Falkland Islands It created a GIS database for the data It analysed spatial data to detect areas of overlaps and potentially at risk of conflicts between activities or between activities and the environment It analysed seabird and seal sighting and tracking data to identify key areas for these groups It produced an MSP framework for FIG presented in a 'Policy paper' that will recommend best practice to implement MSP in the Falkland Islands Three workshops took place:	Phase 1 used a case study to create a tangible output that demonstrated the benefits of the MSP tools to Government. Phase 2 covered three key aspects: a legislative review; developing a strategy for MSP, and an assessment of potential areas suitable for MMAs. This case study looked at assessing current fishing closure areas to see whether they could be considered as sites for wider marine management, known as AFCAS. These areas were based on important biodiversity values and fishing license exemptions established in 1986 (Barton 2002). The AFCAS study involved: A workshop that was attended by industry and local NGOs A public questionnaire A post consultation workshop The post-consultation stakeholder workshop is available to download here. One of the recommendations of the post consultation workshop was to conduct further work in these areas. This was the genesis of Phase "Fine scaling the design of Falkland Islands Marine Managed Areas."	Information from the AFCAS stakeholder workshops concluded that further evidence was needed to support the proposed MMAs. Phase 3 started in 2018 and focused on collecting and collating biological data and analysing economic data to provide further evidence for FIG and stakeholders to understand how the proposed MMAs could impact current and future activities and what biodiversity they preserve. A Project Management Group was established, which helped to steer the project, The Project Management Group comprised three FIG directors (Directorates of Natural Resources, Mineral Resources and Policy and Economic Development), as well as representatives of the Falkland Islands Fishing Companies Association (FIFCA), and the Falkland Islands Petroleum Licensees Association (FIPLA) and a representative from the Shallow Marine Surveys Group (SMSG). Additionally, a Project Stakeholder Group (PSG) was established with 12 representatives from other interested parties and organizations. This technical document provides examples of important elements of the Phase 3 work and it contains four elements: • Inshore proposed Marine Managed Areas • Offshore proposed Marine Managed Areas

Workshop #1 'Setting the scene' – November 2014 The workshop took place on 24-25 November 2014 in Stanley, Falkland Islands and gathered 16 local stakeholders, government representatives and scientists, and 3 international experts. The workshop achieved the following: Defined contexts, vision and objectives for MSP in the Falkland Islands Listed all marine activities and values Identified potential conflicts amongst activities and between activities and values Listed available spatial data, define mapping priorities and identify data gaps **Workshop report** (PDF, 0.5MB) **Workshop #2 'Developing the tools' – April 2015** The workshop took place 16-17 April 2015 in Cambridge, UK, and gathered 7 local government and stakeholder representatives and 15 UK-based MSP experts. Its activities included: • An exploration of maps available for analyses and zoning, complete and/or under progress • It identified missing data or data gaps • It drew a preliminary framework for MSP for the Falkland Islands • It defined the way of categorizing areas for management • From lessons learnt from other MSP experiences, the project identified the main points that influence the effectiveness of MSP process and how to get it right for the Falklands • It listed the key mechanisms for effective science integration into MSP • It Identified and compiled a list of organizations for successful MSP and outreach **Workshop report** (PDF, 3MB)		• Overlap between marine predators and Marine Managed Areas • Economic implications of Marine Managed Areas.

Recommendations were made to the government for a second phase to examine how MSP would be progressed and how the Falkland Islands might include Marine Protected Areas into this process. These became to be known as MMAs.		

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CHAPTER 1
INSHORE MARINE MANAGED AREAS

Image: *Photinula taeniata* (ribboned top shell). Credit: SMSG.

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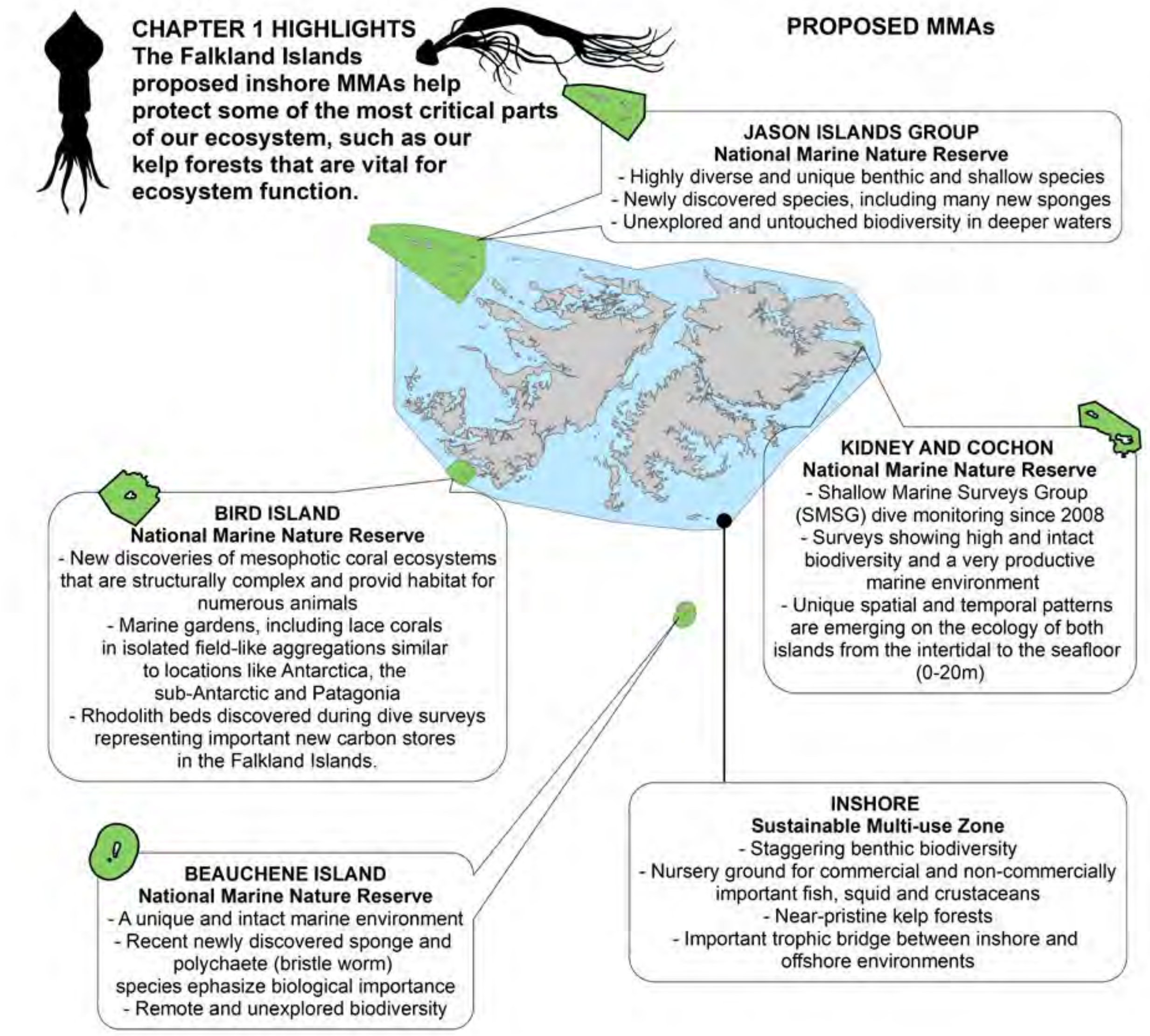

CHAPTER 1 HIGHLIGHTS
The Falkland Islands proposed inshore MMAs help protect some of the most critical parts of our ecosystem, such as our kelp forests that are vital for ecosystem function.

PROPOSED MMAs

JASON ISLANDS GROUP
National Marine Nature Reserve
- Highly diverse and unique benthic and shallow species
- Newly discovered species, including many new sponges
- Unexplored and untouched biodiversity in deeper waters

KIDNEY AND COCHON
National Marine Nature Reserve
- Shallow Marine Surveys Group (SMSG) dive monitoring since 2008
- Surveys showing high and intact biodiversity and a very productive marine environment
- Unique spatial and temporal patterns are emerging on the ecology of both islands from the intertidal to the seafloor (0-20m)

BIRD ISLAND
National Marine Nature Reserve
- New discoveries of mesophotic coral ecosystems that are structurally complex and provid habitat for numerous animals
- Marine gardens, including lace corals in isolated field-like aggregations similar to locations like Antarctica, the sub-Antarctic and Patagonia
- Rhodolith beds discovered during dive surveys representing important new carbon stores in the Falkland Islands.

BEAUCHENE ISLAND
National Marine Nature Reserve
- A unique and intact marine environment
- Recent newly discovered sponge and polychaete (bristle worm) species ephasize biological importance
- Remote and unexplored biodiversity

INSHORE
Sustainable Multi-use Zone
- Staggering benthic biodiversity
- Nursery ground for commercial and non-commercially important fish, squid and crustaceans
- Near-pristine kelp forests
- Important trophic bridge between inshore and offshore environments

CHAPTER SUMMARY

Chapter 1 explores the Falkland Islands nearshore and coastal ecosystems proposed for designation as inshore Marine Managed Areas (MMAs). This chapter covers four examples of recent research by SAERI and SMSG that provide insights into the breadth, diversity and key importance of our nearshore and coastal ecosystems. The proposed MMAs will help to conserve and protect these unique and diverse nearshore and coastal ecosystems.

Chapter 1.1 focuses on our unique and important kelp forests. Kelp blankets the Falkland Islands coasts and is a key species in the function of the Falklands inshore system. The key findings of this chapter include:

- Kelp provides many services to the Falkland Islands and international community. This includes mitigating storm damage, nutrient cycling and providing habitat and productivity to many harvestable resources indirectly through 'trophic bridges' or directly as nurseries or habitat at differing life history stages for many species.
- Kelp forests provide a valuable range of direct and indirect services, which if managed correctly, will continue to benefit people, both now and in the future. The total estimated value of the Falkland Islands' kelp system of *Macrocystis pyrifera* is currently equivalent to ~ £2.69 billion per year (or £3.24 million km^2 per year).
- The *Lessonia* group of species in the Falkland Islands have a greater bathymetric and spatial distribution and thus a greater biomass than *Macrocystis pyrifera*. *Lessonia* spp. kelp species are found in the kelp forest understory meaning they are largely subtidal and therefore not quantifiable from satellite imagery.
- What also remains unknown is the ability of kelp forests to sequester CO2 and therefore help regulate climate. Work in this area is set to increase in the next few years as international efforts to coordinate climate change responses also increase.
- The true value of the kelp forest is beyond monetary value, and maintaining kelp ecosystems in a healthy state will ensure they continue to supply valuable ecological processes, functional roles, and ecosystem services, including their (previously) overlooked role as significant long-term carbon sinks.

Chapter 1.2 explores coastal seaweed to look at biogeographic patterns that highlight the significance of Falkland Islands coastal and shallow marine environment as globally unique. Key findings from this work include:

- The first biogeographical analysis of algae in the southern South Atlantic and the Falkland Islands.
- New taxa recorded in the Falklands by DNA barcoding provides an updated inventory for the Islands.
- This result supports the hypothesis that areas lacking ice cover during the Last Glacial Maximum (LGM) would be more diverse than areas of increased galacial influence. This also supports the likelihood that the Falkland Islands were a refugium for coastal marine flora and fauna during the LGM, with the lack of ice allowing populations to be maintained.
- The absence of glaciation in the Falklands also explains the high algal taxonomic distinctness for the Islands, with the coastal habitats not subjected to perturbation through ice-scour and iceberg calving.
- This study improves the knowledge of macroalgal biogeography in the South Atlantic, linking exposure since the last glaciation to species occurrences in the region.
- It is acknowledged that there are limitations in using open access data for a biogeography study, and ongoing and future genetic work will be integrated to help with understanding these patterns.

WHAT IS BLUE CARBON?

Blue carbon is the carbon stored in nearshore-coastal and marine ecosystems. In tropical ecosystems mangroves, tidal marshes and seagrass meadows are considered key blue carbon habitats. In the Falkland Islands more temperate/subpolar environment, kelp forests are thought to be important sequesters of carbon dioxide, and therefore climate regulators (like the trees of the sea).

WHAT IS ECOSYSTEM SERVICE?

Ecosystem services are broadly defined as "the benefits people obtain from ecosystems" and which improve overall well-being (MEA 2005). Ecosystem services are provided by nature, mostly free of charge, to humanity, such as storm protection and climate regulation. Kelp ecosystems provide a huge range of services to the Falkland Islands.

Chapter 1.3 provides the first description of rocky intertidal zonation around the Falkland Islands and how marine invertebrate communities vary across sites.

- The results of this study suggest that exposure is a greater influence than steepness on the diversity and community structure, likely due to increased wave energy creating a more perturbed environment.
- This study determined that the greatest faunal diversity was found in the north-west of the Falkland Islands.
- South-facing shores exhibiting the lowest diversity.
- The Upper shore is categorised by a high density of Spirorbid annelids. The Middle shore was dominated by limpets *Lottia* sp. and false limpets *Siphonaria lateralis* and *Siphonaria* sp.
- Spirorbid annelids were found to be negatively correlated with boulder and bedrock, instead showing a correlation with cobbles and pebbles. This may be due to competition with limpets and barnacles for space in substrate, therefore favouring smaller rock surfaces.
- The Lower shore is dominated by barnacles *Notochthamalus scabrosus* and bivalve Mytilus edulis chilensis. This species is also known to be extensive in the middle and lower zones of the intertidal Falkland Islands and southern South America.
- In the Middle and Lower shore zones, sheltered flat sites displayed the greatest diversity, with exposed flat sites reduced in the Middle shore and lowest of all in the Lower shore. Beaton (2020) linked this pattern to the wave energy being most intense on the Lower shore and decreasing moving up the Middle and Upper zones. This would result in a high risk of dislodgement from the wave impact, and also increase the ability of more agile taxa to move between the inter- and subtidal zones.
- The significance of these findings in the context of the proposed MMAs are a better understanding of Falkland Islands intertidal environments.

Chapter 1.4 examines the inshore fauna community patterns around the Kidney Island National Nature Reserve.

- This is the first study that quantitatively describes the shallow benthic fauna for the Falkland Islands, and examines community level patterns of change in diversity and abundance at small temporal and bathymetric (depth) scales. These results deliver much needed baseline information.
- Kelp forests are clearly an important marine habitat, providing crucial functions to the ecological community, including nutritional resources, shelter and shade. For example, *Macrocystis* forest communities have a rich faunal diversity globally, with the kelp forests of the Falkland Islands being no exception.
- The three transects resulted in a total 146 taxa, represented by 121,865 individuals, were recorded in this survey, from 21 classes.
- Shallow transects were dominated by red foliose seaweed, with hard substrate covered with encrusting coralline algae. Taxa found to inhabit this stratum included invertebrates known as grazers, for all or part of their diets, and therefore found where algal communities are most abundant. For example, top-snails, whelks and sea urchins.
- Brittle stars were shown to have a negative correlation with bedrock, along with colonial sessile taxa such as bryozoans.
- Bryozoans were found to have the greatest densities in the Middle transects, however depth was not an influencing factor, with bedrock being the most important factor to Bryozoan community structure.
- Deep transects were characterised by a sharp decline in red foliose algae, with coralline algae encrusting bedrock becoming the dominant substrate.
- Temporal variation did not appear to be as significant a factor on the benthic communities as spatial variation. The seasonal trajectories clearly demonstrate variation in community structure following changes in season.

DETAILED CHAPTER OVERVIEW

Chapter 1 provides insight into the Falkland Islands inshore ecosystem as currently delineated by the proposed inshore MMA. What is immediately noticeable about nearshore and coastal Falkland Islands waters is the abundance of wildlife and very dense kelp beds. What is not noticeable from the surface is the very high biological diversity in the flora and fauna.

Kelp blankets the islands and is a key species in the function of this inshore system and it is becoming increasingly clear that it is key to the function of Falkland Islands shelf system too. Work by SAERI (published in Bayley et al. 2021) highlighted just how important giant kelp (*Macrocystis pyrifera*) is in terms of ecosystem services and its potential for blue carbon sequestration. Kelp provides many services to the Falkland Islands and international community. This includes mitigating storm damage, nutrient cycling and providing habitat and productivity to many harvestable resources indirectly through 'trophic bridges' or directly as nurseries or habitat at differing life history stages for many species. What remains unknown is the ability of kelp forests to sequester CO2 and therefore help regulate climate. This has been overlooked in assessments of the beneficial services they provide. The Bayley et al. (2021) study revealed that kelp forests provide a highly valuable range of direct and indirect services, which if managed correctly, will continue to benefit people, and the environment, both now and in the future. The total estimated value of the Falkland Islands' kelp system is currently equivalent to ~ £2.69 billion per year (or £3.24 million km^2 per year). However, the true value of the kelp forest surrounding the Falkland Islands is likely to be higher still, given that our estimate does not account for elements such as associated scientific research, tourism, and cultural services, due to the necessary data currently being unavailable. Similarly, the full value of these highly biodiverse ecosystems in supplying habitat and food to a large range of associated species is crucial, yet extremely difficult to fully quantify. This study illustrates the importance of maintaining kelp ecosystems in a healthy state to ensure they continue to supply valuable ecological processes, functional roles, and ecosystem services, including their overlooked role as significant long-term carbon sinks. The study was unable to make an assessment of the Falkland Islands tree kelp species (*Lessonia* spp.). This group is understory meaning it is largely subtidal and therefore not quantifiable from satellite imagery. However, it is thought that the *Lessonia* group of species in the Falkland Islands have a greater bathymetric and spatial distribution and thus a greater biomass than the giant kelp *Macrocystis pyrifera*. However, while considerable progress has been made in recent years to address knowledge gaps, kelp remains a vastly understudied, but vitally important part of our marine ecosystem.

Similarly, algae remains poorly studied in the Falkland Islands. Ongoing work with the Natural History Museum (NHM), SAERI and SMSG initiated by a Darwin Plus grant have increased our knowledge of Falkland Islands seaweeds. Again, much data were collected and are still being worked up which will provide the Falkland Islands with much needed information about its algae diversity. The work (Brodie et al. 2020) has resulted in the description of one new species, *Corallina chamberlainiae* and insights into the biogeography of Corallinales in the South Atlantic it also highlighted the need for great taxonomic effort in the region. Many species are being examined. It is likely that we have 3 new species of *Lessonia*, 2 new species of notothenioid fish, 3 opisthobranch molluscs and a number of crustaceans all of which are the focus of taxonomic work by partners. Exploration was hampered by the bathymetric range we are able to sample and explore. To date much of this work has been through SCUBA, however, through SAERI and SMSG there are larger vessels, ROVs, side scan sonars, dropdown cameras that are available and will allow research in the greater depths of our nearshore areas.

It is becoming increasingly clear that the Falkland Islands near shore waters have extraordinary biological diversity and genetic diversity (at population levels) compared to southern South America. During the last glacial maximum (LGM), distributions of taxa were known to retreat to refugia for recolonization (Fraser et al. 2009). The Falkland Islands have been shown to be one such refugium, being free from ice during the LGM (Hodgson et al. 2014; Hall et al. 2020), with species rapidly re-dispersing to Patagonia and the surrounding sub-Antarctic from the Falklands' 'founder' populations after the ice retreated (González-Wevar et al. 2018). Evidence of this is published by Nikula et al. (2010) who determined that the populations of crustaceans *Parawaldeckia kidderi* and *Limnoria stephensoni* across the sub-Antarctic displayed a single common descended haplotype, except for the Falklands population which exhibited a greater haplotype diversity. González-Wevar et al. (2016) also found differentiation within a *Nacella mytilina* (kelp limpet) population in the Falkland Islands compared to populations in Patagonia where no heterogeneity was detected. This suggests that the Falklands' populations were maintained throughout the LGM, allowing for a greater genetic diversity. This

HOW DOES GENETIC CONNECTIVITY INFORM CONSERVATION MANAGEMENT?

Genetic connectivity and natural fluctuations will occur through time across the MMAs. Genera such as *Errina* spp. can form a species complex consisting of multiple genetically distinct cryptic species or sub-species. These 'species' tend to be subdivided geographically, to varying degrees of scale; within and between geographic regions. The presence of *Errina* corals at both Bird Island and the most southern proposed MMA at the Burdwood Bank present a unique opportunity to assess the genetic diversity and relatedness of deep-sea coral populations across shallow (40m) and deep (100m+) environments. Sampling across these habitats will also be particularly important to validate onshore to offshore blue carbon pathways. In this manner, some species can be considered 'ecological models' for testing questions of population connectivity. For example, isolated populations are more vulnerable and if impacted by disturbance, are less likely to recover, due to a lack of outside connectivity to re-establish the population. This information can be used by conservation managers to better protect these important ecosystems into the future.

feature of refugia has been highlighted in studies in the Northern Hemisphere, including those by Coyer et al. (2003) and Provan et al. (2005) who determined greater genetic diversity in algal species (*Palmaria palmata* and *Fucus serratus*, respectively) in the English Channel. Kelp rafting has long been considered a mechanism for post-glacial dispersion of marine taxa over long distances. Bull kelp, *Durvillaea antarctica*, likely recolonized regions of the sub-Antarctic from glacial refugia such as the Falklands and New Zealand by this method (Fraser et al. 2010). Little work has been carried out on biogeographic effects of glaciations in the Southern Hemisphere in comparison to the work in the Northern hemisphere. The general patterns and processes of recolonization after glaciation between the two poles are very different, with the Arctic connected to land and the Antarctic surrounded by ocean.

Mesophotic ecosystems are largely unexplored in the Falkland Islands and the lower depth limit of most light-dependent species (e.g., kelp and sponges) is unknown (Bayley et al. 2021; Goodwin et al. 2011; 2012). These habitats constitute complex biodiversity at depths between 30 and 150 m (Hinderstein et al. 2010), where divers cannot easily access, and where key biodiversity gaps exist. In 2019 and 2021, new Stylasterid (lace) coral and *Errina* spp. coral sites were identified at Bird Island, West Falklands, including drop down camera footage of their field-like abundance, similar to the density found in other locations such as the Patagonian Fjords in Chile and East Antarctica (Bax and Cairns, 2014). These observations confirm that Bird Island hosts important mesophotic coral biodiversity, providing further justification for the proposed Marine Management Area (MMA) at Bird Island. Ideally these insights will inform more extensive and well funded research expeditions in the future, that include the capacity to sample specimens at deeper depths and confirm the species identifications.

A SAERI/SMSG and University of Aberdeen PhD student, Emma Beaton, explored some of these patterns with coastal algae in one of her PhD chapters. Genetic sequence results were collated with seaweed records from the Falkland Islands, Strait of Magellan, Beagle Channel, South Georgia and the Antarctic Peninsula from published works and public access databases in order to examine if the algal biodiversity of the regions has been influenced by deglaciation following the Last Glacial Maximum. 2748 records were gathered from the five regions, representing 305 taxa. The Falkland Islands were found to display the greatest algal diversity and taxonomic distinctness, with the lowest species richness observed in South Georgia and the lowest taxonomic distinctness exhibited in the Antarctic Peninsula. A linear relationship between taxonomic distinctness and age of deglaciation was found not to be significant as no evidence of offshore glaciation has been detected in the Falkland Islands. The low taxonomic distinctness in the Antarctic Peninsula, Beagle Channel and South Georgia was attributed to heavy perturbation from iceberg calving and scour across the shallow marine environments decimating algal communities. The absence of glaciation in the Falkland Islands is reflected in the high taxonomic distinctness, allowing the Islands to be a refugium from which algal species recolonized other regions following deglaciation from the Last Glacial Maximum. These patterns in marine fauna are the subject of ongoing research with researchers here within the Falkland Islands and international collaborators.

Inshore research in the Falkland Islands is ongoing and includes the examination of the importance of our inshore waters to the shelf ecosystem. This work is being delivered through a new (2022 – 2024) Darwin Plus grant "Climate change resilience in Falkland Islands fisheries and marine ecosystems". Part of this work will be conducted through a newly created PhD studentship that will explore the role of coastal zooplankton and ichthyoplankton community dynamics in Falklands shelf ecosystem function. Specifically, this research will (i) Create a temporal and spatial baseline of zooplankton, ichthyoplankton and squid paralarval communities in the coastal waters (ii) Elucidate the population dynamics of lobster krill (*Munida gregaria*) from pelagic life history stages to settlement and reproduction (iii) Quantify the role of the Falkland Islands inshore environment as nurseries for commercial squid and fish and (iv) Quantify the role of the inshore environment as a 'trophic bridge' to the shelf ecosystem.

The marine environment that surrounds the Falkland Islands is still an area of scientific discovery. With a huge coastline and small population, research has been generally *ad hoc* and opportunistic in nature. This research is now more systematic and testament to this are new discoveries including new previously unknown habitats and species being described. Since 2010 a good deal of new species have been described including 12 new species of sponge from the Stanley area and the Jason Islands (Goodwin et al. 2011). A further 9 new species of sponge were described from Beauchêne and the Sea Lion Islands and south-east East Falkland. In addition, new polychaete species have been described (Darbyshire, 2013; Darbyshire, 2014; Darbyshire and Brewin, 2015; Darbyshire, 2017). Teresa Darbyshire's PhD work, in collaboration with SAERI and SMSG, resulted in a much-improved knowledge of Falkland Islands Polychaeta in terms of species inventories, descriptions of new species and their biogeography (Darbyshire, 2018). Her work continues, thus far she has reported 218 taxa with only 52 being named.

> Kelp forests blanket the islands and key species enable the healthy function of inshore systems. It is becoming increasingly clear that kelp is also key to the function of the Falkland Islands offshore shelf system too.

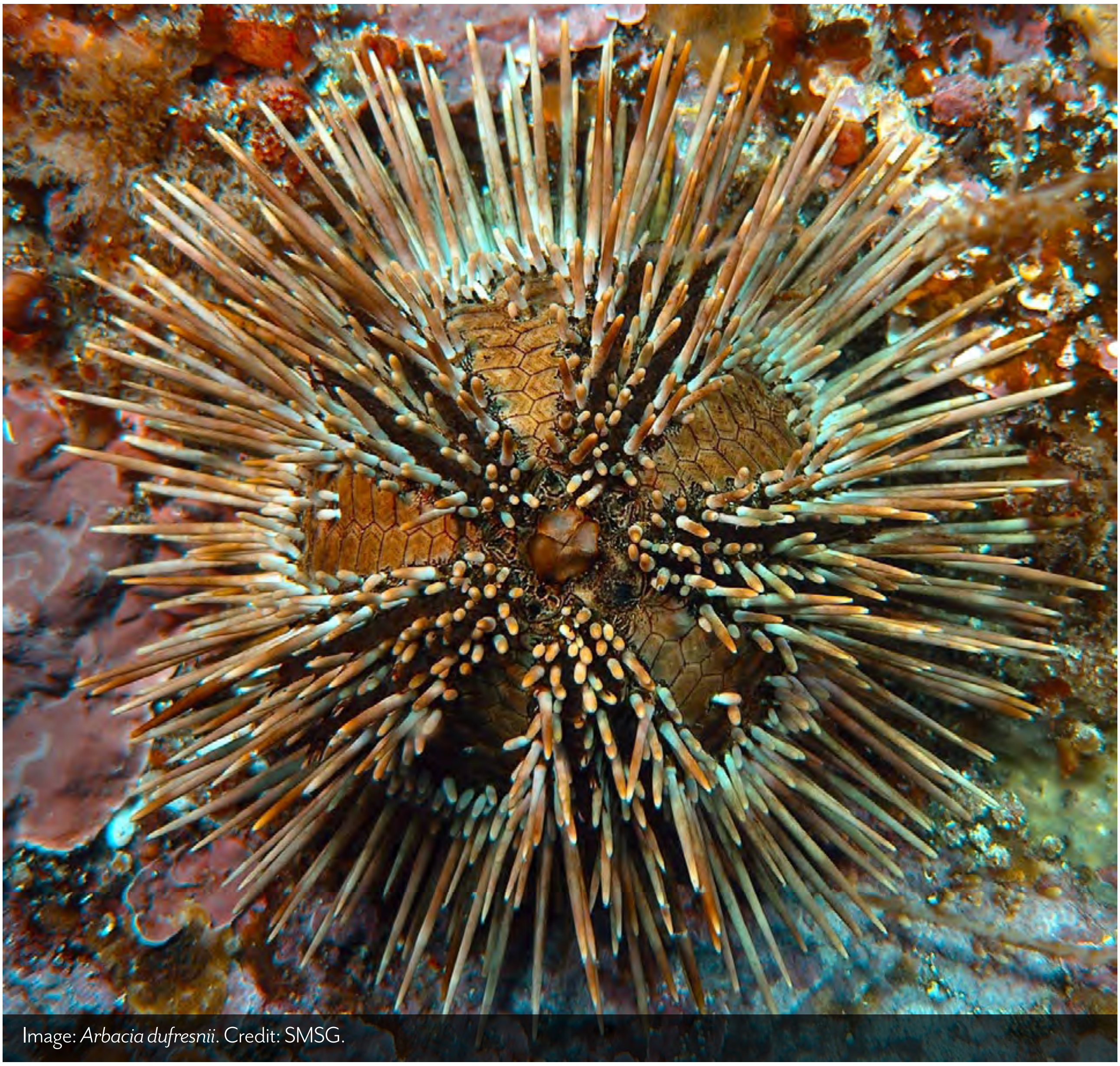

Image: *Arbacia dufresnii*. Credit: SMSG.

1.1 INSHORE: KELP FOREST ECOSYSTEMS AND THEIR SERVICES ACROSS THE FALKLAND ISLANDS

Kelp forests are an important and dominant component of the Falkland Islands coastal zone, providing multiple ecosystem services to people, including mitigating storm damage, cycling nutrients, and providing nursery grounds for commercial fisheries. However, Falkland Islands kelp forests are vastly understudied, but a vitally important part of our marine ecosystem. Work by SAERI and SMSG (published in Bayley et al. 2021) highlighted just how important giant kelp (*Macrocystis pyrifera*) is in terms of ecosystem services and its potential for blue carbon sequestration. Here we show that the total estimated value of the Falkland Islands' kelp system is currently equivalent to ~ £2.69 billion per year (or £3.24 million km per year). Maintaining kelp ecosystems in a healthy state will ensure they continue to supply valuable ecological processes and ecosystem services, including their overlooked role as significant long-term carbon sinks ('blue carbon').

ABSTRACT:

Kelp forests dominate the Falkland Islands coastal zone (Beaton et al. 2020). These important habitats have high growth rates and productivity, rapidly cycling carbon from the surrounding waters into biomass (Wernberg et al. 2018) and provide multiple ecosystem services to people, including mitigating storm damage, cycling nutrients, and providing commercially-harvestable resources. However, kelp forests' ability to sequester carbon dioxide, and therefore help regulate the climate, has until recently, been overlooked in assessments of the beneficial services they

Image: *Macrocystis pyrifera*. Credit: SMSG.

provide. The study by Bayley et al. (2021) incorporated the most up to date knowledge on the potential of kelp to sequester blue carbon, using the extensive kelp forests of the Falkland Islands as a case study to assess the value of kelp forest to society through multiple associated ecosystem services. Their analysis showed that kelp forests provide a sizable range of direct and indirect services, which, if managed effectively over the long-term, benefit ecosystem function and society. In an economic context the total estimated value of the Falkland Islands' kelp system is currently equivalent to ~ £2.69 billion per year (or £3.24 million km^2 per year), based on 2020 carbon price estimates. However, the true value of the kelp forest surrounding the Falkland Islands is likely to be higher still, given their estimates do not account for additionalities such as scientific research, tourism and cultural values often attributed to coastal environments such as wellbeing and quality of life. Furthermore, the full value of these highly biodiverse ecosystems in supplying habitat and food to a large range of associated species is crucial, yet extremely difficult to fully quantify. This study illustrated the importance of maintaining kelp ecosystems in a healthy state to ensure they continue to supply valuable ecological processes, functional roles, and ecosystem services, including their overlooked role as significant long-term carbon sinks (blue carbon).

INTRODUCTION:

Ecosystem services are broadly defined in relation to humans as "the benefits people obtain from ecosystems" and which improve overall well-being (MEA 2005). These coastal services include, for example: storm protection and climate regulation, commercial food and energy resources, recreation and spiritual connections to nature (Martínez et al. 2007, Barbier et al. 2011, Haines-Young and Potschin 2013, Himes-Cornell et al. 2018). Macroalgae beds (e.g., kelp forest), are only found over a small portion of the world's surface area, but are estimated to provide close to half of the world's total ecosystem services (Costanza 1999). The MAES (Mapping and Assessing Ecosystem Services) approach accounts for both ecological processes and human activities (Maes et al. 2012). The outputs of the approach help to meet policy commitments, such as the EU Biodiversity Strategy for 2030 (European Commission 2020), by accounting for these services within a methodological framework.

Falkland Islands kelp forests include mixed macroalgal assemblages of brown algae from the Order Laminariales (Graham et al. 2007). *Macrocystis pyrifera* or 'giant kelp' is a particularly abundant component of the kelp forest assemblage. The second most abundant is the smaller understory kelp *Lessonia* spp. (Graham et al. 2007, Vásquez et al. 2014). *Macrocystis* and *Lessonia* spp. form a foundation habitat which performs a range of important ecological functions (Beaton et al. 2020, Graham et al. 2007) and ecosystem services (Filbee-Dexter 2020, Smale et al. 2013, Vásquez et al. 2014).

There is considerable potential for macroalgae such as kelp to sequester CO$_2$ to deeper waters, where it is locked away long-term in sediments (Filbee-Dexter and Wernberg 2020, Krause-Jensen and Duarte 2016, Queirós et al. 2019), and current global sequestration estimates for all marine macroalgae are ~173 Tg C per year (ranging from 61–268 Tg C per year, the majority through transport into the deep sea (Krause-Jensen and Duarte 2016, Queirós et al. 2019) (Fig. 1.1). Kelp's other important indirect services arise from the diverse range of species which rely on the kelp forest for habitat and shelter (Gaylord et al. 2007, Graham et al. 2007, Nikula et al. 2010). Additional services may include nutrient cycling and coastal protection or the value attained through commercial fishing, recreation, and eco-tourism (Blamey and Bolton 2018, Filbee-Dexter 2020, Smale et al. 2013, Vásquez et al. 2014, Macreadie et al. 2017a).

Bayley et al. (2021) aimed to quantify and estimate the total value of the ecosystem services associated with the Falkland Islands' kelp forests, including their value in sequestering carbon dioxide, known as 'blue carbon'. To do this they used a combination of high-resolution satellite-derived kelp habitat extent predictions and in-situ density measurements. This work built on previous analyses showing extensive kelp assemblages (Golding et al. 2019) and economic benefits from natural systems (Bayley et al. 2017, Bormpoudakis et al. 2019, Smith 2019) to improve the understanding of their value and benefit to society as a whole.

Image: *Doryteuthis gahi* eggs. Credit: SMSG.

Image: *Campylonotus vagans*. Credit: SMSG.

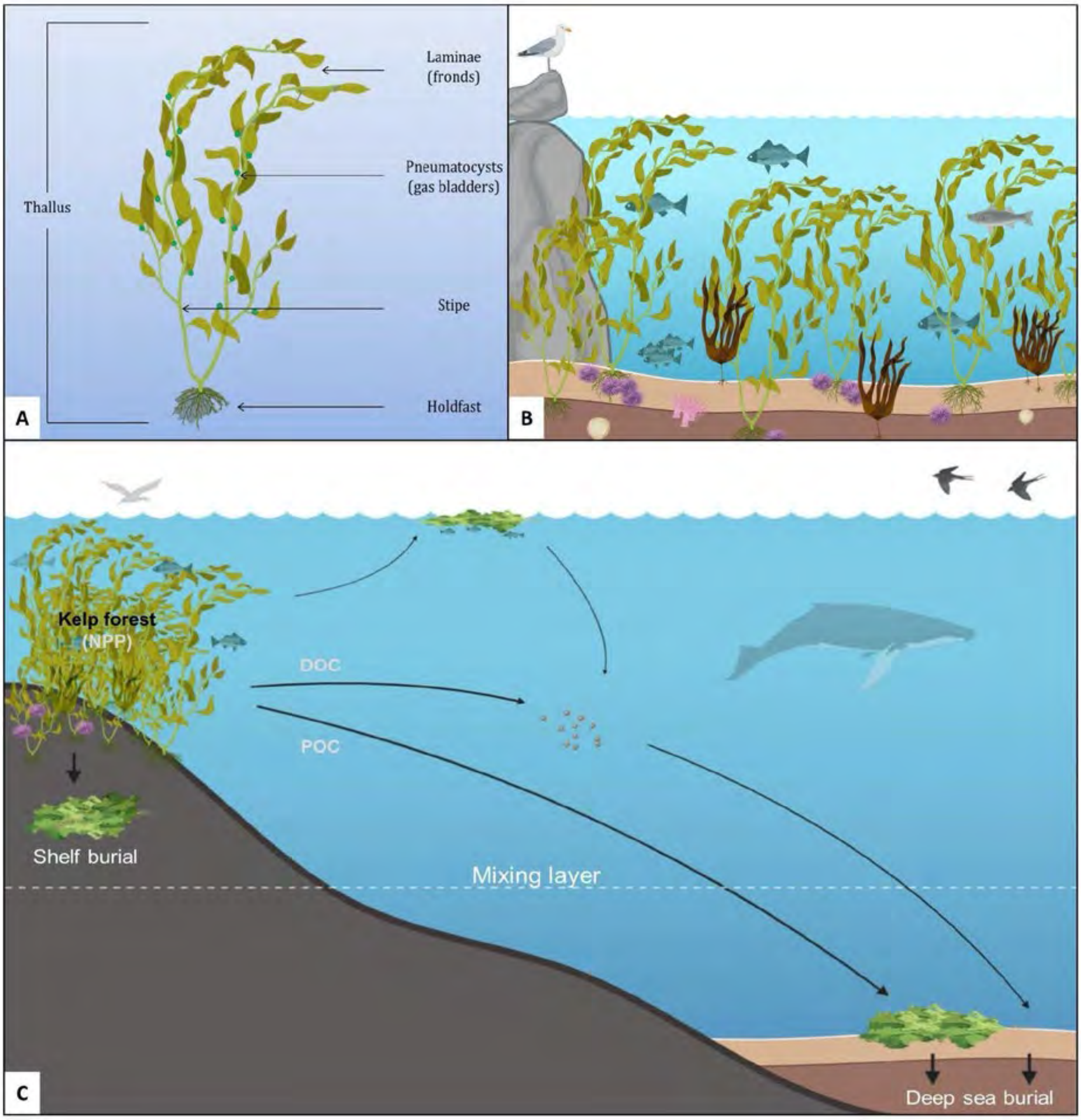

Fig. 1.1: *Diagrams of: A) a typical giant kelp (Macrocystis pyrifera) thallus, illustrating the major components of the adult sporophyte plant life-stage; B) a typical giant kelp forest community structure, including kelp understorey and associated biodiversity; and C) sequestration routes of kelp forest net primary productivity (NPP) biomass to the deep sea through dissolved and particulate organic carbon (DOC/POC) pathways – based on Krause-Jensen and Duarte (2016). Source: Bayley et al. (2021)*

METHODS:

Bayley et al. (2021) used a range of economic valuation techniques to assess the combined ecosystem service value of a mixed *Macrocystis pyrifera* and *Lessonia* spp. kelp forest across the Falkland Islands coastal zones (463,897 km2 Fig. 1.2). Including:
1) the regulating service value of kelp as a climate buffer (through carbon storage and sequestration);
2) the regulating service value of nutrient cycling;
3) the provisioning service of associated commercial fisheries; and
4) the theoretical provisioning service of kelp as a raw material via extraction of alginate/alginic acid (see Bayley et al. 2021 Suppl. material 1A).

Image: *Munida gregaria*. Credit: SMSG.

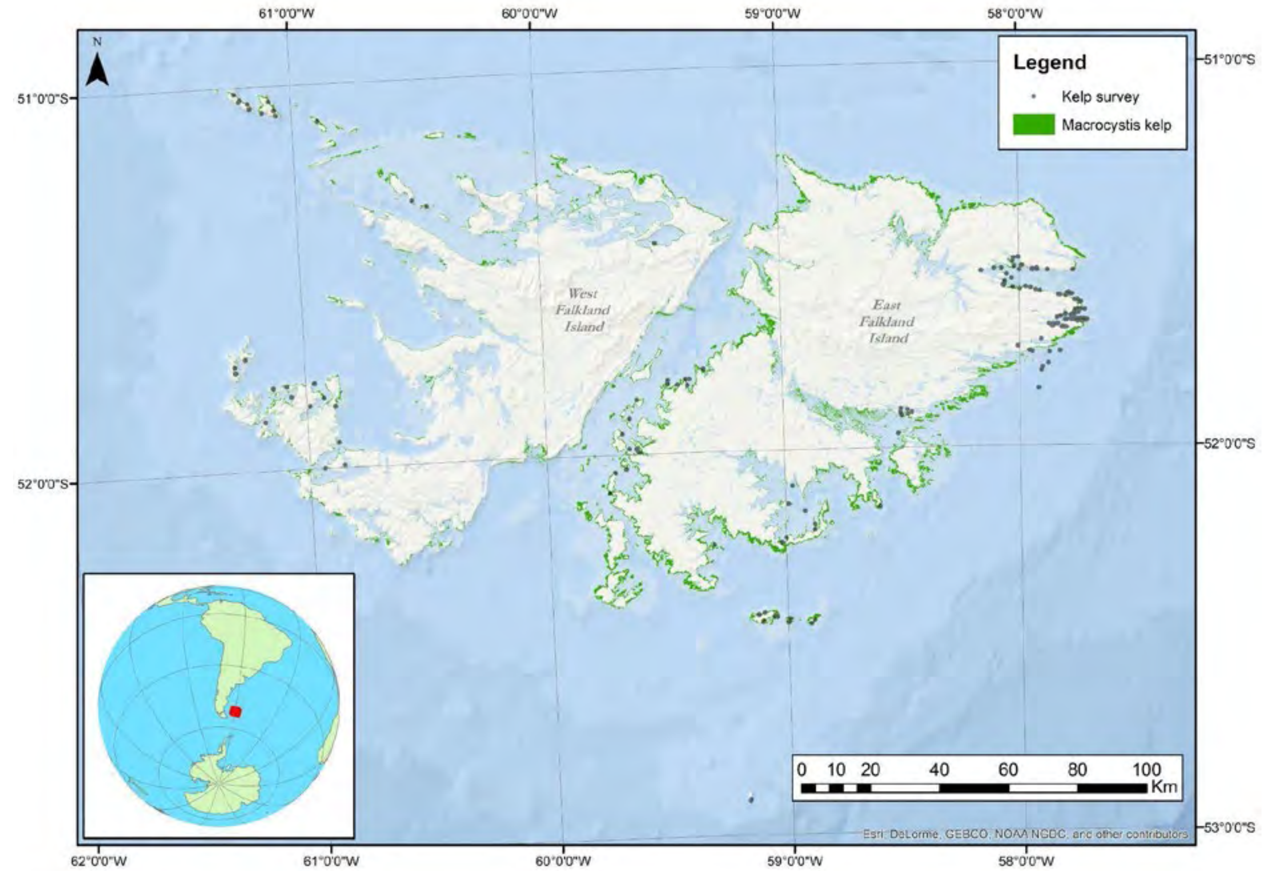

Fig. 1.2: *Mapped distribution of kelp forest (Macrocystis pyrifera) across the Falkland Islands, based on habitat modelling undertaken in 2019 (Golding et al. 2019). Site location points of annual benthic surveys of kelp, conducted between 2008 and 2016 are shown. (Source: Bayley et al. (2021).*

Kelp distribution data was mapped using image classifications based on satellite imagery clipped to the Falkland Islands area of interest. Where possible, ground-truthing points from in-water surveys were additionally included *M. pyrifera* (*Lessonia* spp. mapping proved impossible with this method). For further details on the broad-scale mapping methodology, see Golding et al. (2019). Kelp density was calculated based on SMSG, unpublished data collected from across the Falkland Islands between 2008 and 2016 for a total of 315 surveys (Fig. 1.2). Biomass and carbon content estimation for *Macrocystis pyrifera* was calculated using values from van Tussenbroek (1993) for spring and autumn and multiplied by the mean kelp density observed from surveys conducted during the same season (Table 1.1). The mean weight of carbon per metre squared was multiplied by the calculated extent of *Macrocystis pyrifera* within the Falkland Islands to give a total carbon standing stock, then converted to CO2 using a conversion factor of 3.67 (based on relative atomic weights).

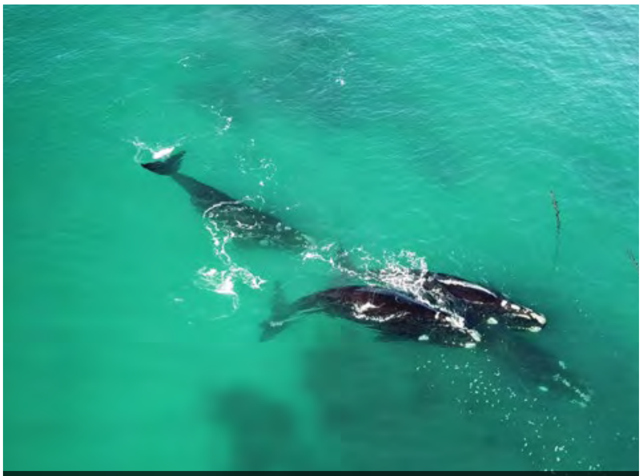

Image: Right whales in Port William. *Credit: SMSG.*

Image: Abundance and diversity. *Credit: SMSG.*

Table 1.1: Published values of total thallus wet and dry weight, mean population density, and carbon content for *Lessonia flavicans, L. trabeculata* and *Macrocystis pyrifera*. * *M. pyrifera* values based on estimations by Reed & Bzezinski (2009). † *M. pyrifera* values adapted from van Tussenbroek (1993), *Lessonia* spp. values adapted from Tala & Edding (2007). Total stored carbon estimated over the 831 km2 mapped Falkland Islands extent. Density values based on overall density of *Lessonia* spp. from 2008-2016 assuming a 50% split of species types. Source: Bayley et al. (2021)

Kelp characteristic	***Lessonia flavicans***		***Lessonia trabeculata***		***Macrocystis pyrifera***	
	Spring	**Autumn**	**Spring**	**Autumn**	**Spring**	**Autumn**
Typical population density (plants per m^2)†	6 ±1	8 ± 3	5 ± 2	5 ± 2	0.62	0.72
Plant biomass wet weight (kg m^2) †	12 ±3	12 ± 4	17 ± 4	21 ± 2	8	1.4
Plant biomass dry weight (kg m^2) †	1.62 ±0.44	2.23 ± 0.60	4.55 ± 1.05	5.78 ± 0.75	0.8	0.14
Dry weight per plant (kg) †	0.27 ± 0.04	0.29 ± 0.12	1.04 ± 0.47	1.28 ± 0.40	1.29	0.19
Dry weight as percentage of wet weight (per plant, i.e. holdfast, stipe, and blades)*	13.7	18.3	26.6	26	10	10
Percentage C g-1 dry weight†	27.23 ±1.07	23.44 ± 1.92	22.32 ± 0.69	21.21 ± 0.75	30	30
Average surveyed density from 2008-2016 (plants m^2)	0.64	0.72	0.64	0.72	0.29	0.25
Average amount of Carbon (kg m^2)*	0.05	0.05	0.15	0.19	0.07	0.01
Total carbon (tonnes)	39,180	40,401	123,705	161,357	57,774	8,716
Total CO2e (tonnes)	143,662	148,137	453,583	591,641	211,838	31,958

Kelp sequestration rates were estimated based on the average net primary productivity (NPP) of *Macrocystis pyrifera* kelp forest (including understorey species) based on Krause-Jensen and Duarte (2016), but to include the context of the Falkland Islands, where kelp primarily grows on hard bedrock, the shelf-burial process is less likely and was excluded from calculations. Carbon values were estimated based on emissions targets for future climate scenarios and the cost of abatement (BEIS 2019) with the proposed high-series non-traded price of carbon set at £103.918 tonne^{-1} CO2e (initially proposed in DECC 2009). Since this period, international emissions targets have become more ambitious (UNFCC 2015) and central carbon cost series are likely under-costing the current central values (DECC 2009, BEIS 2019). Bayley et al. (2021) state that "CO$_2$e cost values were applied to current estimates of carbon content and sequestration potential within the Falkland Islands (based on current density and distribution and assuming no future decline in kelp extent or density). It is important to note that the current value of the carbon already sequestered to the deep sea was not estimated due to lack of data, but is likely substantial".

Nutrient cycling

Bayley et al. 2021 base their nutrient cycling valuation on "the replacement cost needed to recreate the function of coastal nitrogen and phosphorus regulation and recycling back to the land, if this natural service did not exist (Costanza et al. 1998). We use the cost value of $28,916 USD ha^{-1} year^{-1} stated by Costanza et al. (2014). The total extent over which this service value applies to the Falkland Islands was again based on satellite estimates of the total area (hectares) of the kelp forest (Golding et al. 2019)". This service value is likely to be an underestimate of the total Falkland Islands resource, because it is based on kelp which is visible and not deeper-water forest cover. There is also uncertainty in a value per hectare given the limited number of surveys on which the original replacement cost was based (Costanza et al. 1998).

Associated commercial fish stocks/harvests

The average total commercial fish catch (tonnes) was calculated for the Falkland Islands between 2015-2017 (Falkland Islands Government 2018), with a focus on species that spend part of the life-cycle within kelp habitats (Bayley et al. 2021). Data is limited for many of these species, so it was assumed that ''any kelp habitat or near-kelp habitat utilisation of this type at any life-cycle stage is essential for sustaining the whole commercial fishery's population''. Similarly, only fisheries with observational data to support their presence in kelp were included. These data were used to estimate the total value of the kelp system, based on the market value of each species (£GBP/metric tonne), in terms of exploited kelp-associated fish harvest (Falkland Islands Government 2018). Additional values, such as the costs of running the fishery (e.g., fuel, salaries etc) were unavailable for these fisheries, preventing a 'value-added assessment' and government revenue from fishery licence fees for all fisheries associated with the kelp system were averaged from 2015- 2017 with some caveats and a final count of nine relevant target species for this analysis (see Bayley et al. 2021 Suppl. material 1B and Suppl. material 1C).

Alginate production

Bayley et al. (2021) used a non-use valuation technique, based on a historic alginate extraction pilot project in the 1970s (Shackleton 1976) and an economic study in the 1980s that proposed ''obtaining a licence to harvest kelp at a minimum annual wet tonnage of 350,000 tonnes''. This proposed market collapsed in the UK by 1982 (Shackleton 1982), and by using historic theoretical production levels Bayley et al. (2021) were able to to contextualise the likely income from this resource if it were utilised in modern times. The average export price of dry *Lessonia* spp. kelp out of Chile in 2009 for the alginate industry equates to £917 per tonne (Bixler and Porse 2011 based on 2020 estimations).

Results:

Modelling outputs using remote sensing data gave an estimated 830.1 km^2 coverage of kelp forest surrounding the Falkland Islands in 2019 (Fig. 2).

Carbon storage

The overall values of *Macrocystis pyrifera* density were highly variable, ranging between ~ 0.02 and 2.75 thalli/m2 across all surveys, with a mean value of 0.293 thalli/m^2 (SE = ± 0.051) in spring, averaged across all years (Bayley et al. 2021). Autumn density values were similar at 0.249 thalli/m^2 (SE = ± 0.039) averaged across all years. Overall values of Lessonia spp. Density was again highly variable, ranging between 0.025 and 4.4 thali (whole plants)/m2 across all surveys, with a mean value of 0.642 thalli/m^2 (SE = ± 0.069) in spring, averaged across all years. Autumn density values were 0.716 thalli/m^2 (SE = ± 0.082) averaged across all years (Bayley et al. 2021).

These seasonal density values resulted in an average of 0.12 million tonnes of CO2e estimated to be stored in standing M. *pyrifera* vegetation, with a spring peak density equivalent to 0.21 million tonnes CO2e. The average overall CO2 stored by Lessonia spp. in the Falkland Islands is 0.30 million tonnes of CO2e in spring and 0.37 million tonnes of CO2e in autumn, assuming an equal proportion of L. *flavicans* and L. *trabeculata* within all surveys. Total seasonal CO2e stored by standing kelp plants across the Falkland Islands (within the aerially-mapped extent) and respective biomass values are shown in Table 1.1.

Applying the mean productivity value of 985 g C m^2 yr^{-1} (Reed and Bzezinski 2009), and the estimated percentage of DOC and POC sequestered to deep sea (Krause-Jensen and Duarte 2016), the average carbon sequestration value for the Falkland Islands is 0.081 Tg carbon yea^{r-1}. This is equivalent to 0.299 million tonnes of CO2, as shown (with corresponding maximum and minimum estimates) in Table 1.2.

Table 1.2: Rounded minimum, average, and maximum estimated values of carbon sequestered from the Falkland Islands kelp forests per year, based on current known distribution and NPP rates of 670-1300 g C m$_2$ yr^{-1}. Source: Bayley et al. (2021).

Sequestration route	Carbon year-^{1}		
	Minimum	Average	Maximum
POC buried in shelf (Tg)	0.005	0.007	0.009
POC exported to deep sea (Tg)	0.013	0.019	0.025
DOC exported below the mixed layer (Tg)	0.038	0.056	0.074
Total sequestered blue carbon (Tg)	0.055	0.081	0.107
Total sequestered CO2 (million tonnes)	0.203	0.299	0.3945

Bayley et al. (2021) report that ''the combined total peak estimate of CO2 equivalent carbon stored in standing giant and understorey kelp species within the satellite-derived mapped extent of kelp forest in the Falkland Islands is 0.58 million tonnes. Averaged (central estimate) total sequestration to the deep sea is 0.299 million tonnes of CO2 annually. Based on non-traded high-series carbon dioxide equivalent (CO2e) values (BEIS 2019), of £103.9 per tonne CO2e, present-day standing stock of carbon stored in Macrocystis and Lessonia kelp is equivalent to £60.27 million. The annual value of carbon sequestered to deep sea sediments is estimated to be approximately £31.07 million per year''.

Nutrient cycling

Coastal algae and seagrass beds were estimated to contribute a total of £2.4 billion per year, based on remote-sensed kelp distribution (Table 1.3) following the methods of Costanza et al. (2014) as of 2011 (based on the 2007 USD purchasing power parity) (Bayley et al. 2021).

Table 1.3: Indirect value calculations for the nutrient-cycling benefit of Falkland Islands kelp systems, based on remote-sensed total area. USD = United States Dollars, GBP = Great British Pounds. Source: Bayley et al. (2021).

Value parameters	Indirect value
Total area of kelp (Falkland Islands)	830 Km2
Total area of kelp (Falkland Islands)	83,009 Ha
Value of nutrient cycling of seagrass / algae beds (based on 2011 values in USD ha^{-1}, from Costanza et al. (2014), Costanza et al. (1998))	$28,916.00 ha-1 year^{-1} 1
Total value in 2007 USD yr-1 (based on Costanza et al. (2014)) for the Falkland Islands	$2.40 Billion year^{-1}
Conversion from 2007 USD to 2020 USD with inflation (1$ = 1.25$)	$3.00 Billion year^{-1}
Total value (conversion from USD to GBP at 0.8)	£2.40 Billion year^{-1}

Associated commercial fisheries

Bayley et al. (2021) found that "six of the 15 major fisheries within the Falkland Islands were found to be reliant on kelp for some period of their life-cycle, based on current knowledge. This includes the kingclip (*Genypterus blacodes*), Patagonian scallop (*Zygochlamys patagonica*), Patagonian squid (*Doryteuthis gahi*), Red cod (*Salilota australis*), Rock cod (*Patagonotothen* spp.), and Southern blue whiting (*Micromesistius australis*). Collectively, these fisheries total an annual harvest value of £129,291,813 (~ 24% of the total commercial fishery harvest value), and £7,049,575 in licence fees (equivalent to ~ 36% of the total licence revenue) for the Falkland Islands". The authors further state that "It is important to highlight that while kelp provides habitat directly to these species, the biological and oceanographic influence of kelp to the nearshore environment will also trigger potentially large indirect effects on a range of other species, through trophic links which we are unable to assess fully here".

Alginate extraction

Based on the Shackleton (1982), Bayley et al. (2021) estimated the "viable annual wet tonnage extraction of 350,000 tonnes (i.e. ~ 5% of the Falkland Islands' kelp area impacted), the total dry weight of kelp for export would be approximately 70,000 tonnes, (assuming *Lessonia* spp. dry weight as 20% of wet weight). Applying the Chilean export value of £917 tonne^{-1} would lead to a (non-use) revenue value of £64.19 million year^{-1}. In the initial Shackleton (1982) economic assessment, the Falkland Islands Government (FIG) would receive licence royalties, which would be equivalent to ~ £147,057 year^{-1} in present value after inflation".

Cumulative value of assessed kelp services

Table 1.4 displays a summary of annual and spatial value estimates for all services investigated during this study. Values for other services including tourism, scientific research, culture, and coastal protection are still currently unknown or data-limited in this region, and are therefore not included within the summary.

Table 1.4. Summary value estimates of services associated with giant kelp forest in the Falkland Islands in 2020. Overall, remotely-mapped kelp extent for spatial estimates = 830.1 km^2. * Blue carbon stock value given assuming the standing stock is protected over ten years and applying the future projected CO2e value. Full values for tourism, scientific research, culture, and coastal protection are still currently data-limited or unknown. Source: Bayley et al. (2021).

Service	Value estimate (£GBP year^{-1})	Spatial value estimate (£GBP km2 year^{-1})
Blue carbon stock	0.703 million*	84,721
Blue carbon sequestration	31.07 million	37,436
Nutrient cycling	2,400.29 million	2.89 million
Associated commercial fisheries value	126.3 million	152,177
Alginate industry (non-use)	64.19 million	77,337
Total	2,692.17 million	3.24 million

Discussion

Bayley et al. (2021) found that the total estimated value of the assessed ecosystem services which are provided by the Falkland Islands' satellite-mapped kelp forests was ~ £2.692 billion per year (or £3.24 million GBP km^{-2} year^{-1}) based on 2020 market-based values. These estimates represent the first quantified basis for development of contemporary kelp management strategies on the Patagonian Shelf, as well as a value to form a basis from which future estimates can be made under various climate change scenarios. Whilst attention for blue carbon is garnering global attention presently, there are a number of ecosystem services discussed in Bayley et al. (2021) and nutrient cycling by kelp forests was found to be the most valuable service provided by the ecosystem in terms of monetary value (£2.4 billion per year). However, these estimates are based on values outside of the Falkland Islands (Peters et al. 2019, Roleda and Hurd 2019) and more data is needed. The next most valuable services were fisheries and then the climate-buffering service of carbon sequestration blue carbon. Carbon standing stock value was comparatively low relative to the other services, and the authors attribute this to seasonal differences throughout the year as the kelp grows and dies-back (Vásquez et al. 2014, Graham et al. 2007). Consequently, the value of carbon storage is expected to increase over time in concert with the increase in trading values of market-based carbon credits.

These estimates have important applications for kelp management. For example, in terms of the climate buffering benefits from carbon capture, ''the Falkland Islands likely sequesters 0.299 million tonnes of CO2 annually (at a conservative minimum estimate). This amount represents an additional annual contribution of approximately 0.1% of current UK net emissions (364.1 million tonnes CO2e/year in 2018) towards their Nationally Determined Contribution (NDC) legally committed through the Paris Agreement''. Whilst this contribution is small in number, this is a year after year national-scale positive benefit to global planetary health, and it costs nothing. This benefit is derived from simply maintaining the natural kelp environment in its current distribution and condition.

Bayley et al. (2021) suggest three thematic areas for future work on Kelp ecosystems.

1) Long-term data on the annual variation in the extent of kelp forests around the Falkland Islands. This step will enable the quantification of trends in abundance and distribution to understand changes over time. More detailed analyses and predictions on depth and density/condition (health) of the kelp would also allow for improved estimates of total biomass and management. For example, the lower depth limit is unknown for *Macrocystis* in the Falkland Islands presently, and the Bayley et al. (2021) methods assume a consistent density across the distribution and uses known biomass estimates from kelp collected at ~ 5 m only (van Tussenbroek 1993). Consequently, total biomass estimates are underestimated. Furthermore, individual species' average biomass by height, and Falkland Islands-specific total NPP values for kelp forest would help refine future analyses (Filbee-Dexter and Wernberg 2020).

2) Research into understory kelp such as *Lessonia* spp. because their extent is larger than that of *Macrocystis pyrifera*, and the full extent is unknown. Furthermore, the vertical extent of deeper-water kelps from all species (not visible from the surface), would improve management strategies (and likely increase the overall valuation amount significantly). The collection of acoustic backscatter data to identify presence of vegetation is a possible option for future mapping to Increase confidence in total kelp distribution around the Falkland Islands in deep water (Kenny et al. 2003). This method, if combined with in-water benthic surveys to allow species distribution modelling (Elith and Leathwick 2009) would also improve valuation estimates and improve our knowledge of overall biodiversity in the Falklands. Bayley et al. (2021) also suggest that ''Remote-sensed satellite data on wave exposure (i.e. from Sentinel-1 Radar), would further help parametrise modelling, and allow informed predictions to be made of coastal protection services from kelp''.

3) Research that quantifies the amount of carbon already sequestered and locked away in deep sea sediments from the kelp forests over time. This value is likely to be substantial and should be a consideration for any future commercial activities in deep highly sedimented areas.

Fisheries harvest

''Licence fees from fisheries which are associated with the kelp forest systems amount to an average annual revenue of £7,049,575 to the Falkland Islands Government or £8,493 km^{-2} of kelp''. Bayley et al. (2021) evaluated the harvested commercial catch which does not account for additional non-commercial or unharvested fish dependent on the natural ecosystem (dolphins/whales and others). The harvest value is also subject to changes based on market prices, catch quotas and emerging commercially valuable markets. Negative impacts on the fisheries' life-cycle could be associated with or influenced by the kelp forest, and the commercial fishery is likely reliant on the maintenance of these habitats into the future. However, we have limited information on planktonic species and trophic linkages, and research on the fisheries that may be indirectly linked to kelp is an important area in need of further research.

Nutrient cycling

Bayley et al. (2021) state that ''The greatest individual ecosystem service value comes from kelp's ability to recycle nutrients and clean coastal waters. Without appropriate management of kelp forest systems, this service may become degraded, lowering the overall water quality surrounding the coasts and reducing productivity in associated fisheries that utilise these nutrients (Bertocci et al. 2015, Beaton et al. 2020, Jiang et al. 2020, Pfister et al. 2019). The replacement cost of this regulation service through artificial processes would be extremely costly and inefficient. The reduction in water quality through increased turbulence and phytoplankton without kelp (Narayan et al. 2016, Gaylord et al. 2007, Pfister et al. 2019) and associated loss of biodiversity and function linked to kelp forest (Graham et al. 2007), would also likely have negative impacts for the tourism value of this area, through reduced underwater and beach aesthetics (González and Holtmann-Ahumada 2017)''.

Kelp harvest

A cost-benefit analysis of how the alginate industry would impact the other ecosystem services and the important associated biodiversity is a key consideration before any future developments in this area. Bayley et al. (2021) also state that ''Carbon market values, the market values of harvested kelp-associated fish and kelp itself for the alginate industry, can also rapidly change. This is demonstrated well in the 171% increase in the export value of Lessonia-derived alginate from 1999 to 2009 (Bixler and Porse 2011)''.

Kelp services for future analysis

Marine systems hold important cultural services for their livelihoods or well-being (Rodrigues Garcia et al. 2017, Martin et al. 2016), and in this context, it is difficult to assign a monetary value to a particular habitat or location (Blake et al. 2017), and beyond the scope of the present study. However, these services are valuable in the Falklands where the economy is centred on a healthy marine ecosystem (Bormpoudakis et al. 2019, Smith 2019). This difficulty could come from our inability to quantify something 'priceless' to most people. There is also an innate difficulty in trying to value any ecosystem in isolation, because all of this is inextricably linked.

Nature-based tourism also brings significant revenue (Spalding et al. 2017) and locations with large kelp systems and existing tourism infrastructure receive revenue, for example through diving, snorkelling, wildlife tourism and recreation (Blamey and Bolton 2018, Loomis 2006, Viana et al. 2017). Bayley et al. (2021) state that ''Tourism in the Falklands (focused on wildlife viewing and historic sites) is valuable, with 57,496 cruise visitors and 1,884 land-based leisure tourists during 2017/18''.

The coastal protection is an important service afforded to islands by nature (Narayan et al. 2016, Martínez et al. 2007). Valuations of these benefits are typically based on costs of building man-made barriers and defences or avoided costs of damage to nature and infrastructure (Barbier et al. 2011, Narayan et al. 2016). The Falkland Islands 2016 census defined two hubs of population and infrastructure are in the naturally sheltered capital of Stanley and the inland RAF military base. The monetary value of kelp forests in terms of storm damage mitigation is not yet possible to quantify, for such low lying islands, this could become a concern in the future.

Finally, kelp is considered a foundation species and ecosystem engineer, the ecological and functional roles of this habitat and the species which rely on it has been the focus of much scientific research and monitoring to date. This is another with a broader value for society through the creation of knowledge. The Falkland Islands kelp systems attract researchers from across the world and contribute to multiple Falklands-based science organisations, such as the SAERI, Falkland Islands Government, Falklands Conservation, and British Antarctic Survey. They also attract researchers from universities, institutes and museums globally. Bayley et al. (2021) state that ''detailed data quantifying research grants and expenses relating specifically to kelp research were limited, again preventing the inclusion of this service within our present analysis''.

Future change

Falkland Islands kelp forests are vastly under-studied. Work by Mora-Soto et al. (2021), which included Falkland Islands Researchers Dr Paul Brewin and Neil Golding, characterised 309 giant kelp forests in the Channels and Fjords of Southern Chile, Falkland Islands, and the island of South Georgia by their coastal geospatial attributes. Statistically significant variables were included in a conditional inference tree to predict kelp forest size. Sea surface temperature (SST) records were analysed to confirm temperature ranges over the last four decades. Nautical charts, historical surveys, aerial photogrammetry, unmanned aerial vehicle (UAV) surveys and satellite imagery were overlaid to assess spatial distribution of kelp forest canopies, spanning the period 1829–2020. Considering the extensive natural and human caused changes over the last two centuries, kelp ecosystems were remarkably persistent.

Nevertheless, Bayley et al. (2021) caution that ''The Falkland Islands' kelp system appears to be healthy and stable based on the data currently available. However, a great deal of uncertainty still exists over how this and other kelp habitats globally will fare into the future (Smale et al. 2013, Sutherland et al. 2020). In the 'state of the environment' and Biodiversity Framework reports produced by Falkland Islands Government (FIG Environmental Planning Department 2016, Otley et al. 2008), a number of risk factors are identified for kelp, which need to be appropriately managed


Image: *Mytilus edulis chilensis*. Credit: SMSG.

to avoid any degradation (and subsequent loss of value) of this system. As is typical of many small island nations, high priority threats are from potential invasive species and biosecurity issues. Medium and low threats come from development (i.e., habitat conversion) in coastal regions, pollution, and potential oil spills from exploration and extraction in the region. Any unregulated fishing activities, potential increases in land-based nutrient flows from farming practices, and the potentially damaging effects of tourism also need to be managed. Overarching all of these threats are the potential direct and indirect effects associated with future climatic change (Krumhansl et al. 2016, Smale et al. 2019)''. Over the short-term, Bayley et al. (2021) suggest to maintain all the ecosystem service benefits identified herein and those that can not be assessed and limit the impacts of localised threats, sustained local management and monitoring of kelp condition are needed (Macreadie et al. 2017b, Krumhansl et al. 2016), protection is key. Not only for the services directly utilised by humans, but also the important and abundant associated biodiversity supported by the kelp systems (Beaton et al. 2020, Duarte et al. 2020, Filbee-Dexter 2020). These biodiverse ecosystems provide the basis of many ecosystem services and improves the value of services and biodiverse systems are more likely to be sustainable (Isbell et al. 2015, Beaton et al. 2020, Graham et al. 2007) and maintain interconnection and resilience as well as aid dispersal of sessile benthic fauna (Lowman et al. 2019, Nikula et al. 2010). These important ecological connections maintain functional nearshore processes (Smale et al. 2013, Steneck et al. 2002), diverse ecosystems are also potentially a source of chemicals and medicines. Furthermore, these systems hold an inherent value in and of themselves and for future generations (Smale et al. 2013, Filbee-Dexter 2020). Whilst monetary value is difficult to quantify, the ongoing function and health of these systems and their associated species is paramount to everything discussed herein (Sanchirico and Mumby 2009, Nash et al. 2017).

Conclusion

Bayley et al. (2021) concluded that ''the Falkland Islands' kelp forests supply a range of valuable services to people, which are important both locally and globally. Thanks to the area's geographical isolation and low population, the kelp system currently appears healthy and stable. If future detrimental environmental changes, such as increased local pollution, introduction of unsustainable fisheries, or rapid temperature rise were to occur, we would expect to see declines in terms of habitat distribution and condition. If the system were to decline on a large scale, the loss of direct ecosystem service benefits to the Falkland

Islands and the loss of wider benefits to the world through its indirect services, would be substantial and costly. Close monitoring of habitat extent and active management of local stressors will be key to the long-term stability of the system, and ensure continued flow of multiple ecosystem services to society".

Ongoing work:
Bax et al. (in review) are attempting to build on this work by investigating the role of Falkland Islands macroalgal systems as important blue carbon habitats. Kelp forests are still contentiously described as blue carbon (typically being located on hard rock rather than on soft sediment capable of long-term storage). Nevertheless, there is growing evidence for their ability to sequester biomass to surrounding deeper waters, i.e. being transported to stable sediment beyond the turbulent mixing layer, and potentially having a substantial role in carbon sequestration (Filbee-Dexter and Wernberg, 2020; Krause-Jensen and Duarte, 2016; Smale et al. 2018).

As the knowledge of macroalgal distribution and potential sequestration rates increases (Pedersen et al. 2021; Queirós et al. 2019; Smale et al. 2021), their likely role in global carbon storage is becoming more prominent. In terms of the climate buffering benefit from carbon capture, Bayley et al. (2021) conservatively estimated that the Falkland Islands may sequester in the order of 0.299 million tonnes of CO2 annually. However, a range of assumptions are currently included in such estimates.

Due to their large size and ability to raft at or near the surface, it is possible to map shallow-water extent of *Macrocystis pyrifera* with good confidence, and this has been applied to the Falkland Islands (Golding et al. 2019; Houskeeper et al. 2022; Mora-Soto et al. 2020). However, this method is still limited by factors such as water clarity, wave action, and water depth (i.e. to ~10m max). Alongside, *M. pyrifera*, smaller kelp species found in the Falkland Islands include the two 'tree kelps', *Lessonia vadosa* and *Lessonia flavicans*, and the 'bull kelp' *Durvillaea antarctica* (Beaton et al. 2020; Mora-Soto et al. 2021). These smaller species do not raft at the surface, and often occur in deeper water or are obscured within the understorey, making them difficult to map accurately (Golding et al. 2019). All kelps also experience changes in their extent and biomass according to annual/seasonal cycles and level of wave exposure making survey timing important (Beaton et al. 2020; Graham et al. 2007). Similarly, estimates of typical biomass and carbon storage per thali are currently highly averaged (Bayley et al. 2021).

With these limiting factors in mind, confidence in kelp distribution around the Falkland Islands could be improved through the collection of acoustic (bathymetry and backscatter) and hydrographic data. This will help identify presence and type of vegetated benthic habitat, and the environmental factors which drive their distribution (Kenny et al. 2003; Rattray et al. 2015). Combining this with systematic in-water benthic surveys and use of remote-sensing tools will improve species distribution modelling estimates (Jayathilake and Costello, 2020; Mora-Soto et al. 2020).

Once the extent and condition of the kelp source is parameterised, quantification of the amount of carbon already sequestered within deep sea sediments over time will be necessary (Atwood et al. 2020). Sediment depth, type, rate of sedimentation, bioturbation and average disturbance (from human or natural impacts) will all influence the amount of carbon currently stored locally/regionally now and in the future (Atwood et al. 2020; Green et al. 2018; Macreadie et al. 2017a; Van De Velde et al. 2018).


Image: *Zygochlamys patagonica*. Credit: SMSG.


Image: *Enteroctopus megalocyathus*. Credit: SMSG.

1.2 INSHORE: BIOGEOGRAPHY OF FALKLAND ISLANDS SEAWEEDS AND THE ROLE OF THE LAST ICE AGE IN FORGING CONTEMPORARY DIVERSITY PATTERNS

This chapter is taken and adapted from PhD research undertaken by Dr Emma Beaton at SAERI/SMSG and the University of Aberdeen. Beaton, E. C. (2020). Shallow Benthic and Intertidal Ecology of the Falkland Islands. PhD Thesis, University of Aberdeen. pp 222.

Beaton (2020) studied the geographic distribution of coastal algae (i.e., the biogeography of algae) from the Falkland Islands, Strait of Magellan, Beagle Channel, South Georgia and the Antarctic Peninsula. 2748 records were gathered from the five regions, representing 305 taxa. Beaton (2020) aimed to enhance the knowledge of algal biogeography in the southern South Atlantic by answering the following questions: (1) Can DNA barcoding improve upon the current macroalgal floral inventory of the Falkland Islands? (2) How does the algal diversity of the Falklands relate to the nearby regions in the South Atlantic? (3) Has ice-coverage during the Last Glacial Maximum (about 20,000 years ago) had an influence on algal taxonomic diversity of the southern South Atlantic?

The Falkland Islands were found to display the greatest algal diversity and taxonomic distinctness, with the lowest species richness observed in South Georgia and the lowest taxonomic distinctness exhibited in the Antarctic Peninsula. A linear relationship between taxonomic distinctness and age of deglaciation was found not to be significant as no evidence of offshore glaciation has been detected in the Falkland Islands. The low taxonomic distinctness in the Antarctic Peninsula, Beagle Channel and South Georgia was attributed to heavy perturbation from iceberg calving and scour across the shallow marine environments decimating algal communities. The absence of glaciation in the Falkland Islands is reflected in the high taxonomic distinctness, allowing the Islands to be a refugium from which algal species recolonized other regions following deglaciation from the Last Glacial Maximum. These patterns in marine fauna are the subject of ongoing research with researchers here in the Falkland Islands and international collaborators. Studies such as this make important steps in understanding the macroalgae communities in the South Atlantic and improve upon the regional knowledge of algal diversity in the Falkland Islands.

Image: The seastar *Cosmasterias lurida* on *Macrocystis pyrifera* (giant kelp). *Credit Dr. S Carter*

ABSTRACT

It is becoming increasingly clear that the Falkland Islands near shore waters have extraordinary biological diversity and genetic diversity (at population levels) compared to southern South America. During the last glacial maximum (LGM), distributions of taxa were known to retreat to refugia for recolonization (Fraser et al. 2009). The Falkland Islands have been shown to be one such refugium, being free from ice during the LGM (Hodgson et al. 2014; Hall et al. 2020), with species rapidly re-dispersing to Patagonia and the surrounding sub-Antarctic from the Falklands' 'founder' populations after the ice retreated (González-Wevar et al. 2018). Evidence of this is published by Nikula et al. (2010) who determined that the populations of crustaceans *Parawaldeckia kidderi* and *Limnoria stephensoni* across the sub-Antarctic displayed a single common descended haplotype, except for the Falklands population which exhibited a greater haplotype diversity. González-Wevar et al. (2016) also found differentiation within a *Nacella mytilina* (kelp limpet) population in the Falkland Islands compared to populations in Patagonia where no heterogeneity was detected. This suggests that the Falklands' populations were maintained throughout the LGM, allowing for a greater genetic diversity. This feature of refugia has been highlighted in studies in the Northern Hemisphere, including those by Coyer et al. (2003) and Provan et al. (2005) who determined greater genetic diversity in algal species (*Palmaria palmata* and *Fucus serratu*s, respectively) in the English Channel. Kelp rafting has long been considered a mechanism for post-glacial dispersion of marine taxa over long distances. Bull kelp, *Durvillaea antarctica*, likely recolonized regions of the sub-Antarctic from glacial refugia such as the Falklands and New Zealand by this method (Fraser et al. 2010). Little work has been carried out on biogeographic effects of glaciations in the Southern Hemisphere in comparison to the work in the Northern hemisphere. The general patterns and processes of recolonization after glaciation between the two poles are very different, with the Arctic connected to land and the Antarctic surrounded by ocean.

INTRODUCTION

The Falklands Current divides the archipelago into cold-temperate and sub-Antarctic climates, as a result of the flow of cold water of the Antarctic Circumpolar Current through the Drake Passage (Arkhipkin et al. 2013; Sabitini et al. 2016). With the Islands experiencing two different conditions, the algal flora will likely show similarities to floras in both Patagonia and South Georgia, and possibly as far as the Antarctic Peninsula. There is currently a lack of knowledge of algal distribution around the Falkland Islands and the South Atlantic, and it is not known to what extent the marine flora of the Falklands is related to the cold-temperate and sub-Antarctic populations. There is currently a lack of knowledge of algal distribution around the Falkland Islands and the South Atlantic, and it is not known to what extent the marine flora of the Falklands is related to the cold-temperate and sub-Antarctic populations. There have been a limited number of studies that include biogeographical patterns of flora and/or fauna in the South Atlantic. McDowall (2005) assessed biogeographical patterns of flora and fauna of the Falkland Islands, yet this study did not include any marine organisms. Griffiths and Waller (2016) studied the patterns of distribution of intertidal invertebrates of the Antarctic and sub-Antarctic regions, which included data from the Falklands consisting of four studies across seven sites. Algal distribution was examined by Wiencke et al. (2014) in the SCAR Biogeographic Atlas of the Southern Ocean in (De Broyer et al. 2014), which studied biogeographical patterns of marine flora and fauna across the Southern Ocean and southern South Atlantic, however this study only included six seaweed species from the Falklands.

During the last glacial maximum (LGM), distributions of taxa were known to retreat to refugia for recolonization (Fraser et al. 2009). The Falkland Islands have been shown to be one such refugium, being free from ice during the LGM (Hodgson et al. 2014), with species rapidly re-dispersing to Patagonia and the surrounding sub-Antarctic from the Falklands' 'founder' populations after the ice retreated (González-Wevar et al. 2018). Evidence of this is published by Nikula et al. (2010) who determined that the populations of crustaceans *Parawaldeckia kidderi* and *Limnoria stephensoni* across the sub-Antarctic displayed a single common descended haplotype, except for the Falklands population which exhibited a greater haplotype diversity. González-Wevar et al. (2016) also found differentiation within a *Nacella mytilina* population in the Falkland Islands compared to populations in Patagonia where no heterogeneity was detected. This suggests that the Falklands' populations were maintained throughout the LGM, allowing for a greater genetic diversity. This feature of refugia has been highlighted in studies in the Northern Hemisphere, including those by Coyer et al. (2003) and Provan et al. (2005) who determined greater genetic diversity in algal species (*Palmaria palmata* and *Fucus serratus*, respectively) in the English Channel. Kelp rafting has long been considered a mechanism for post-glacial dispersion of marine taxa over long distances. Bull kelp, *Durvillaea antarctica*, likely recolonized regions of the sub-Antarctic from glacial refugia such as the Falklands and New Zealand by this method (Fraser et al. 2010). Little work has been carried out on biogeographic effects of glaciations in the Southern hemisphere in comparison to the work in the Northern hemisphere. The general patterns and processes of recolonization after glaciation between the two poles are very different, with the Arctic connected to land and the Antarctic surrounded by ocean.

Research into the algal diversity in the South Atlantic has been ongoing since the late 19th century. Some of the first collections were made on board research expedition vessels *Hessler* and *Albatross* with naturalists producing crude herbarium specimens from algae collected from the Straits of Magellan (Taylor 1930, 1939). At the beginning of the 20th century Skottsberg, as part of the Swedish Antarctic Expedition, recorded the distribution of kelps in the sub-Antarctic and Southern South America (Lewander 2002; Skottsberg 1904). His doctoral thesis on the algae of the Sub-Antarctic and Antarctic regions provided an in-depth review of the marine flora of the regions (Skottsberg 1907, 1941). Despite this early work in the field, there still remain major gaps in knowledge on algal diversity across the South Atlantic.

The Falkland Islands are home to some of the largest kelp beds in the world (van Tussenbroek 1989a). Due to the remoteness of the Islands and the inaccessibility of much of their coastline, little is known about the algal communities and diversity of the Falkland Islands. Some of the early insights into algal diversity were provided by Vallentin (Cotton 1915; Vallentin 1924). Van Tussenbroek (1989a, 1989b, 1989c, 1989d, 1989e, 1993) has provided many valuable insights into the growth, morphological variation and life-span of M. pyrifera in the Falklands. Clayton carried out an extensive survey of Falklands algae, collecting more than 350 herbarium specimens representing approximately 180 species (Clayton 2003 unpubl. data). Much work has been done in recent years to enhance the knowledge of algal diversity in the Islands using genetic sequencing. Broom et al. (2010) employed molecular techniques to understand the relationships between Porphyra species in the Islands. Most recently, Mystikou et al. (2016) identified nine new records in the archipelago and Küpper et al. (2019) described a new species of Dictyota (D. falklandica). Despite the ongoing work in this field, significant gaps in knowledge remain of the marine flora in the Islands, with Küpper and Kamenos (2018) highlighting the lack of knowledge of kelp forests and coralline red algal beds.

METHODS

Biogeographical Patterns

The taxa identified based on the DNA barcoding, along with identifications produced by Mystikou (2015; Mystikou et al. 2016) were compiled together, along with algal distribution data obtained for the Falkland Islands; South Georgia and the South Sandwich Islands; Strait of Magellan, Beagle Channel, and the Antarctic Peninsula, obtained from the Global Biodiversity Information Facility (GBIF) database (GBIF 2019a, b, c, d, e); the Ocean Biogeographical Information system (OBIS) database (OBIS 2019) and Griffiths and Waller (2016). Only taxa identified to genus level or lower were included in the dataset. Where possible, duplicate records were removed, and species names were checked and corrected using AlgaeBase (Guiry and Guiry 2019) and World Register of Marine Species (WoRMS 2019). Taxa recorded in the GBIF as paleobiological were also removed. As this study focuses on the intertidal and shallow subtidal, any taxa collected at a depth greater than 20 m were removed. Each recording was mapped using QGIS (3.8.1 2019) (Fig. 1.3), where co-ordinates were not provided, entries were plotted using the description of where the specimen was recorded/collected or plotted to a general coordinate for the region. A number of different grid sizes were assessed visually and 10 km^2 was chosen as it provided a good balance between representativeness of records contained within each grid and spatial resolution to provide detail throughout the region (Fig. 1.3). A 'buffer zone' was then applied (Fig. 1.3), reaching 1 km both seaward and landward, where any points found out with this zone were considered to be at a depth greater than 20 m or likely to be made in error were removed from the dataset. Given the various sources which provide records to open access databases (including historic records), it was assumed that a variety of different methods were employed to note positions of samples taken and that the buffer was sufficient to account for these errors. A total of 2880 records were removed in preparation of the dataset, leaving 2748 for the analyses.


Image: *Doryteuthis gahi*. Credit: SMSG.


Image: *Aulacomya ater*. Credit: SMSG.

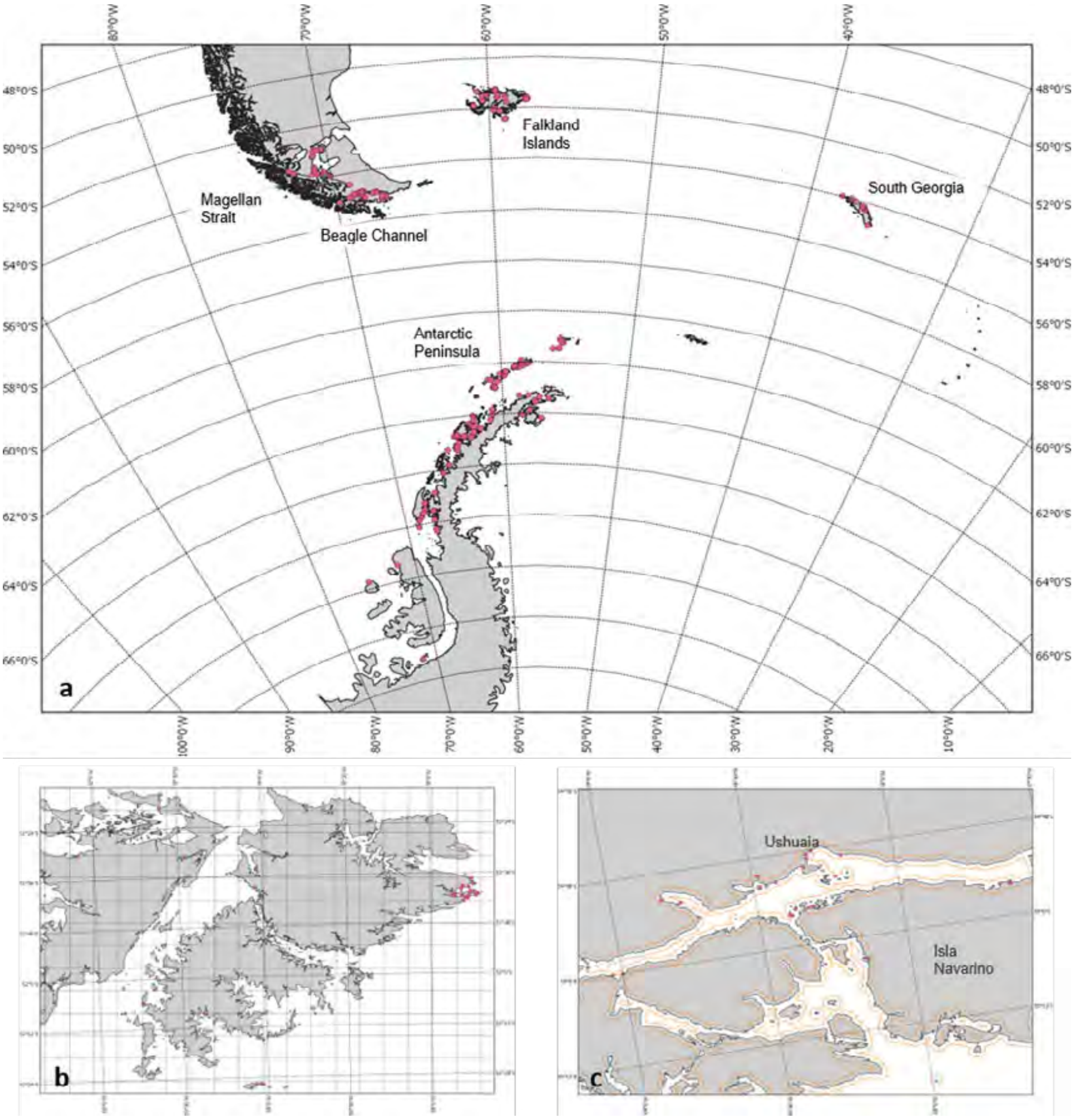

Fig. 1.3: *Maps representing (a) study regions and points of algal records (b) example of 10 km grid (superimposed onto the Falkland Islands) (c) example of 1 km buffer (surrounding the coast of the Beagle Channel).*

Image: *Bunodactis octoradiata*. Credit: SMSG.

Image: *Margarella violacea.* Credit: SMSG.

Data Analyses

Species accumulation curves using the UGE (Ugland, Gray & Elingsen) estimator (Ugland et al. 2003) with 9999 permutations were carried out to standardise the data and determine the sampling effort in each region. The UGE estimator is used to estimate species richness over large regions, by separating the sample region into subregions and calculating a species accumulation curve from random samples within each subregion. Curves are then obtained for every combination of pairs of subregions, which are used to create a total species curve. The total species curve allows for an estimation of the total number of species to be calculated for each sample region (Ugland et al. 2003). Non-metric multidimensional scaling (nMDS) plots were used to visualise the differences in algal communities between the regions, based on the Bray-Curtis similarity matrix of presence-absence transformed data. Nine grid points were found to be strong outliers from the rest of the dataset. The taxa found within these grids were low in number and very rare for the regions which raised questions on the validity of the identifications, and thus were removed from the dataset. Average taxonomic distinctness (AvTD or Δ+) and variation in taxonomic distinctness (VarTD or Δ+) were performed on the subset of data, transformed to presence-absence, to assess the taxonomic distance between pairs of taxa. Average taxonomic distinctness is the measure of taxonomic distance of between each pair of species within the dataset (Clarke and Warwick 1998; Tolimieri and Anderson 2010), while the evenness with which the taxa are distributed within the hierarchy can be examined through the variation in taxonomic distinctness measure (Magurran 2011). Taxa were then separated into the three phyla; Chlorophyta, Ochrophyta and Rhodophyta; in order to examine the taxonomic distances of each group more closely. Normality test was performed using the Shapiro-Wilk test, with both datasets (all taxa and phyla groups) displaying non-Gaussian distribution, followed by Kruskal-Wallis test and Dunn's test for multiple comparisons. Mean taxonomic distinctness for each study region was plotted against age given for deglaciation at the end of the Last Glacial Maximum (LGM) (calibrated years ago). A Spearman r correlation and simple linear regression were then calculated to examine the relationship. Univariate analyses were carried out in GraphPad Prism (v8.2.0 2019) and multivariate analyses were performed using PRIMER version 7 statistical software (Clarke et al. 2016).

Biogeographical Patterns

A total of 2748 algae recordings were gathered from across the five selected regions of the South Atlantic, comprising 315 taxa. 143 grids were used to plot the records. As previously noted, nine grids were removed from analyses due to outlying results, leaving 2732 recordings of 305 taxa in 134 grids. The species accumulation curve, displayed in Fig. 1.4, shows the Falkland Islands to have the greatest algal richness out of the five regions surveyed, with South Georgia exhibiting the lowest richness. However, the sample size was far lower than that of the other four regions. Despite having a greater number of grids, the diversity of the Antarctic Peninsula was lower than that of the Falklands. No curve reaches an asymptote, confirming that more species inhabit all study regions than were captured in the data.

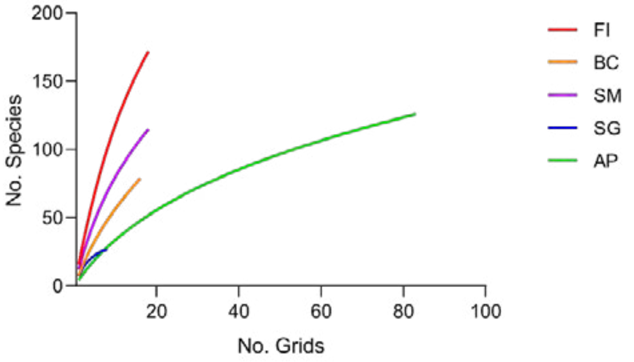

Fig. 1.4: *Species accumulation curve for each study region (where AP= Antarctic Peninsula, BC= Beagle Channel, FI= Falkland Islands, SG= South Georgia and SM= Strait of Magellan).*

Non-metric ordination in Fig. 1.5 shows the algal communities of the Antarctic Peninsula differ greatly from the other four regions, with the Falkland Islands and Strait of Magellan being most similar to one another than to any of the other regions. There is a clear divide between the algal flora of the Antarctic Peninsula from the other study regions (first plot of the Fig. 1.5), with a slight overlap of these regions into the points representing the Antarctic Peninsula.

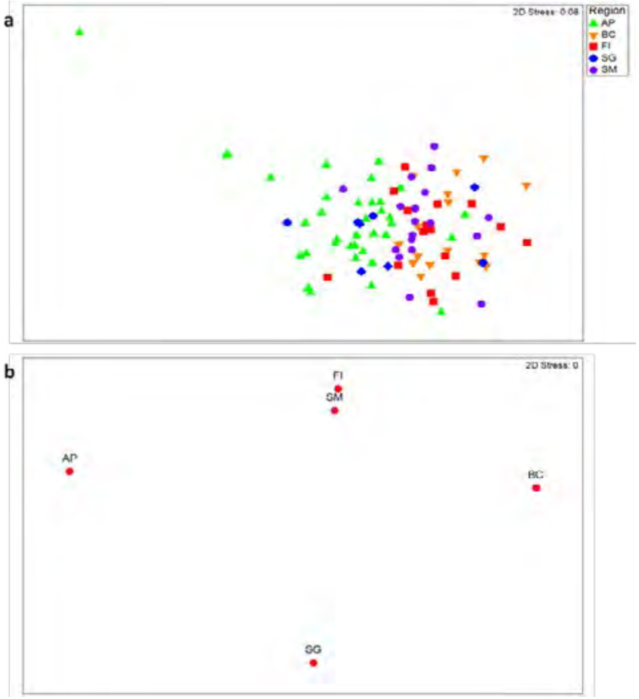

Fig. 1.5: *nMDS plots displaying differences in algal communities in non-dimensional space (where AP= Antarctic Peninsula, BC= Beagle Channel, FI= Falkland Islands, SG= South Georgia and SM= Strait of Magellan).*

The average taxonomic distinctness (AvTD) and variation of taxonomic distinctness (VarTD) are shown in Fig. 1.6. The Falkland Islands were shown to have the greatest AvTD, with a mean of 77.03, and the Antarctic Peninsula displaying the lowest mean of 28.38. Variation in taxonomic distinctness (VarTD) is also shown to be highest in the Falklands and lowest in the Antarctic. The Beagle Channel and Strait of Magellan exhibit AvTD means of 68.54 and 63.69, respectively, however the mean VarTD is far lower in the Beagle Channel than in the Magellan Strait. In the Beagle Channel mean VarTD was 206.55, whereas the Strait of Magellan had a mean of 280.11, demonstrating the Beagle Channel displays greater distances between species but less variation between these distances, in comparison to the Magellan Strait. AvTD and VarTD varied significantly when examined between the three algal phyla. On all counts, the AvTD and VarTD were lowest in the Antarctic Peninsula, except in the average distinctness in Ochrophyta, where the Beagle Channel displayed lowest taxonomic distinctness with a mean of 32.61.

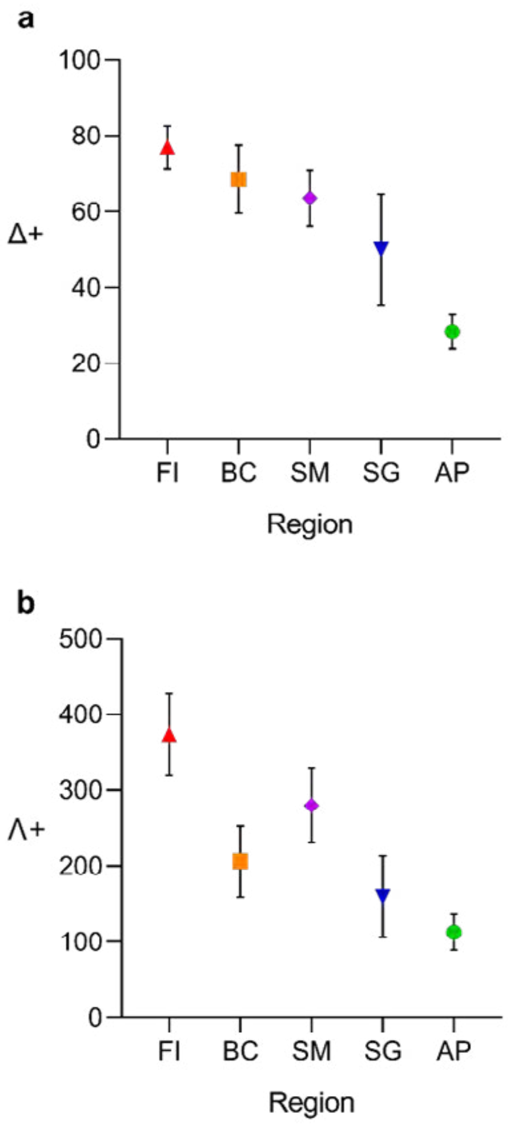

Fig. 1.6: *Taxonomic distinctness Δ+ (a) and variation in taxonomic distinctness Δ+ (b) of each study region (where FI= Falkland Islands BC= Beagle Channel, SM= Strait of Magellan, SG= South Georgia and AP= Antarctic Peninsula).*

Through the Kruskal-Wallis one-way test, paired comparisons between Antarctic Peninsula vs. Beagle Channel and Antarctic Peninsula vs. Falkland Islands were found to be significant with a *P* value of <0.005 for both pairings. Within the separate phyla, no pairs were found to be significant in the Ochrophyta (H= 2.006, *P*= 0.7347)-; Antarctic Peninsula vs. South Georgia and Antarctic Peninsula vs. Strait of Magellan were found to be statistically significant (P=<0.005) within the Chlorophyta (H= 23.16, P= 0.0001) and Antarctic Peninsula vs Strait of Magellan was found to be a significant pair in the Rhodophyta (H= 25.46, P= <0.0001), with a P value of <0.05. Fig. 1.7 shows the AvTD and VarTD of the Ochrophyta, Chlorophyta and Rhodophyta phyla. Within the brown algae, the AvTD is fairly consistent, with all regions within the range of 32-42, with the Falklands displaying the highest mean of 41.12. The evenness of taxa within the Ochrophyta was much greater in Strait of Magellan with a mean value of 72.40 with South Georgia displaying no even distribution, caused by the low sample size. In contrast, South Georgia showed the greatest taxonomic distinctness in the Chlorophyta, despite having the lowest sample size, and the Antarctic Peninsula displayed the lowest distinctness with means of 53.47 and 14.51 respectively. Again, the highest mean for VarTD within the green algae was in the Magellan Strait ($\bar{x}$ = 98.66), followed by the Falklands ($\bar{x}$ = 83.58), with the Antarctic Peninsula displaying the lowest variation with a mean of 37.5. The Strait of Magellan displayed the highest mean of AvTD and VarTD in the Rhodophyta with means of 43.81 and 52.51 respectively. The Antarctic Peninsula also displayed the lowest mean for both distinctness and variation of distinctness (AvTD $\bar{x}$ = 15.5, VarTD $\bar{x}$ = 16.7), with the Falklands also exhibiting low mean values of 18.09 for AvTD and 24.54 for VarTD.

Image: *Choromytilus chorus*. Credit: SMSG.

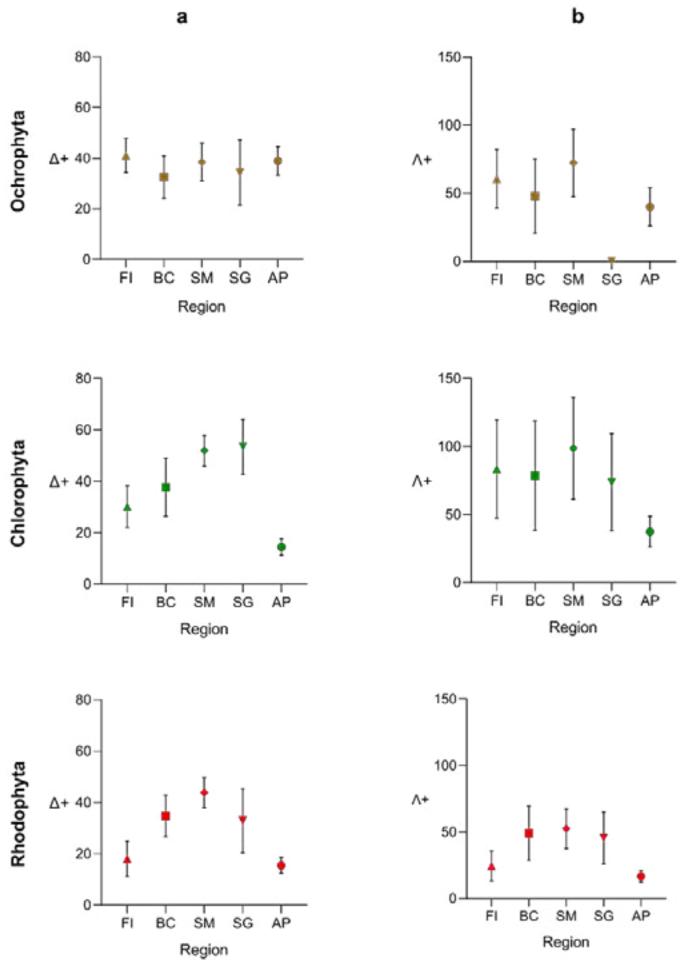

Fig. 1.7: Taxonomic Distinctness Δ+ (a) and variation in taxonomic distinctness Δ+ (b) of algae phyla of each study region (where FI= Falkland Islands, BC= Beagle Channel, SM= Strait of Magellan, SG= South Georgia and AP= Antarctic Peninsula).

For four of the five study regions, there was a pattern of increased taxonomic distinctness, with an increase in time since deglaciation. However, the result for South Georgia does not follow this pattern, displaying the second highest AvTD but a deglaciation age of only 10,000 calibrated years. The Antarctic Peninsula was shown to have experienced the most recent deglaciation, 6,000 years ago, also exhibited the lowest AvTD of 28.38. The Falkland Islands displayed the highest AvTD and greatest years since deglaciation at 22,000?? years ago. Although the Beagle Channel appears to have undergone deglaciation at a similar time to South Georgia, 11,000 years ago, the AvTD is lower than that of South Georgia and the Strait of Magellan which became ice-free 13,000 years ago. The Spearman rank correlation found this relationship not to be significant (r= 0.700, *P*= >0.005). The data on deglaciation for each region was obtained through an examination of the literature and is displayed in Table 1.5.

Table 1.5. Age of deglaciation for each study region

Region	Age of Deglaciation	Source
Falkland Islands	22,000?? cal. yr ago Calculated as age at glaciation. No bathymetric evidence of glaciation extending offshore during LGM.	Hodgson et al. 2014
Beagle Channel	11,000 cal. yr ago	Hall et al. 2013
Straits of Magellan	13,000 cal. yr ago	Boyd et al. 2008
South Georgia	10,000 cal. yr ago	Graham et al. 2017
Antarctic Peninsula	6,000 cal. yr ago	Ingólfsson et al. 2003

Discussion

The Falkland Islands were shown to be the most species rich out of the five regions studied. The new taxa recorded in the Falklands by DNA barcoding provides an updated inventory for the Islands, suggesting the diversity is greater than that recorded in the Antarctic Peninsula which was previously suggested by Griffiths and Waller (2016) to be the more diverse region. The species curves do not reach an asymptote, indicating that not all species present in each region were captured in the dataset. The steep inclination of curves of the Falkland Islands, Beagle Channel and Strait of Magellan suggests that species richness is likely to be significantly higher. This result supports the hypothesis that areas lacking ice cover during the LGM would be more diverse than areas of increasing coverage. This also supports the likelihood that the Falkland Islands were a refugium for seaweeds during the LGM, with the lack of ice allowing populations to be maintained.

The ordination displays a distinct separation of the Antarctic community from the communities further North. In the second ordination plot, a divide between the Antarctic algal community and the seaweed communities of the four other areas is clearly visible, demonstrating that the Antarctic algal flora differs greatly from the regions with no or partial ice-coverage. It is likely that algal communities of the Antarctic Peninsula were eliminated as a result of ice scouring during the LGM, and macroalgal communities are still susceptible to ice scouring today (Barnes and Souster 2011; Mystikou et al. 2014). Therefore, recolonization of the region by algae would have been over a much longer period, due to the greater distance from founding populations (Fraser et al. 2009). Average taxonomic distinctness also supports the hypothesis of the Falklands being a refugium, with greatest overall AvTD and within the phylum Ochrophyta. Consistently lowest mean of AvTD and VarTD for the Antarctic Peninsula supports the hypothesis that age of ice cover is a significant factor in the algal communities of the regions, with full ice cover in the Antarctic leading to lower taxonomic variation. When looking at the three phyla separately, AvTD was lowest in the Antarctic Peninsula for both Chlorophyta and Rhodophyta. This reflects the distribution of green and red algae in shallow waters, and seaweeds being mostly absent in intertidal regions of the Antarctic due to high disturbance from ice abrasion against the benthos, which is increasing in recent years due to reductions in winter ice and an increase in ice shelf calvings (Barnes et al. 2014). Extreme fluctuations in temperature, salinity and UV radiation also accounts for diminished diversity in the intertidal of the Antarctic (Mystikou et al. 2014; Griffiths and Waller 2016). South Georgia was found to have the greatest taxonomic distinctness for Chlorophyta, despite green algae representing only 11% of the algal flora (Wells et al. 2011 unpubl. data), but VarTD showed a lower variation in taxonomic distance. The Magellan Strait displayed the highest AvTD for Rhodophyta of all regions studied. The AvTD of the Ochrophyta shows a different pattern to the Chlorophyta and Rhodophyta plots with smaller changes between regions. This is indicative of the widespread distribution of brown seaweeds and represents differences in community structure of the regions, such as *D. antarctica* dominating rocky coasts around the sub-Antarctic with the exception of South Georgia which is devoid of the bull kelp (Fraser et al. 2009; Nikula et al. 2010), and the replacement of Laminariales with Desmarestiales in the Antarctic (Moe and Silva 1977).

A linear relationship was found between the age of deglaciation and AvTD but was found to not be significant. This is a result of the lack of robust deglaciation estimation for the Falkland Islands. No bathymetric evidence of glaciation extending offshore has been found in the Falkland Islands (Hodgson et al. 2014). The absence of offshore glaciation in the Falklands also explains the high taxonomic distinctness for the Islands, with the coastal habitats not subjected to perturbation through ice-scour and iceberg calving. The relationship between AvTD and age of deglaciation for South Georgia does not follow the linear pattern displayed in the other study regions. There has been debate for some time as to the extent of glaciation across South Georgia, with arguments for glaciers extending out to the shelf break while others maintain a limitation of the glaciation to near-shore (Clapperton et al. 1989; Bentley et al. 2007) The most recent studies support the latter theory of extensive glaciation up to the shelf break, with deglaciation in some areas occurring approximately 10,000 cal. years ago (Graham et al. 2017). The study by Graham et al. (2017) also found evidence of multiple periods of glaciation through the detection of morainal banks within troughs of the shelf break. The contrasting relationship of AvTD and deglaciation in the island can likely be attributed to these subsequent glaciation events. With the exception of the tip of Tierra del Fuego, the entirety of the Beagle Channel was glaciated during the LGM (Hulton et al. 2002), with deglaciation occurring around 11,000 cal. years ago (Hall et al. 2013). The vast coverage of ice resulted in a greater number of calvings and, therefore, a greater extent of algae eliminated from the marine habitat in the eastern region. The increased ice-scour would have prevented long-lived algal species (as well as invertebrate species) from establishing, creating space for opportunistic species to settle. This heavy perturbation of the Beagle Channel accounts for the lower AvTD found in this study. The glaciation in the Strait of Magellan was not as extensive as farther south in the Beagle Channel, with ice coverage restricted up to the area around Punta Arenas (Hulton et al. 2002). The region was completely deglaciated by approximately 13,000 years ago (Boyd et al. 2008). With an ice cap extending across the western portion of the Magellan Strait, any icebergs broken away from glaciers would have moved east across the ice-free regions, causing this area to be highly disturbed from ice abrasion across the subtidal and intertidal environments. Deglaciation of the Antarctic Peninsula following the LGM was most recent, with total deglaciation occurring 6,000 cal. years ago (Ingólfsson et al. 2003). However, the shallow marine environments of the Antarctic Peninsula are still subjected to frequent scour from sea-ice and glacial-ice (Brown et al. 2004; Barnes et al. 2014), preventing the survival of long-living species such as kelps (Moe and Silva 1977; Fraser et al. 2009).

It is acknowledged that there are limitations in using open access data for a biogeography study, however this study does provide a useful result and dataset, delivering the first biogeographical analyses of algae in the southern South Atlantic and the Falkland Islands. It is highly likely that a number of these taxa are misidentified cryptic species, requiring genetic analysis to provide a species-level identification. There is also a high likelihood that morphotypes of the same species will have been mistaken for different species, causing a number of synonyms to be considered as accepted names. Again, DNA barcoding would be required to provide a definite, reliable identification. Sampling effort is also a limitation to the analysis of algal distribution. A large number of the recordings are from a small number of locations in each region due to difficulties in accessing remote areas (Hortal et al. 2007). For example, in the Falkland Islands the majority of the records are from Stanley, the only town in the Islands, or from the nearby coast, within walking distance or short drive. A high number of records have also been made at North Arm in East Falkland. Although anecdotal evidence suggests that this area exhibits a high algal diversity, we hypothesise that this is in fact due to intense sampling effort in this area. Using open access databases also limits the number of herbarium specimens included in the dataset, with only a small fraction of specimen sheets digitised (Yesson et al. 2007). Herbaria are a treasure trove for biodiversity with many specimens sitting for decades before being described. For example, in angiosperms, Bebber et al. (2010) suggested that more than half of all undescribed species had already been collected and are awaiting taxonomic description. With an estimation of over 350 million specimens worldwide (Lavoie 2013), digitising herbarium specimens for entry is extremely time-consuming and only 10% of specimens had been digitised up to 2009 (Nic Lughadha and Miller 2009). Although a number of herbaria globally are digitising their specimens, many small research groups and institutions do not have the money or personnel for such a task. While diversity databases provide access to a vast number of records from numerous surveys, there are inconsistencies in the quality and quantity of the detail provided (Yesson et al. 2007). As the records are made by thousands of individuals the information (such as geographic coordinates, photo of specimen and depth) provided within the records can vary significantly, even entries within surveys where multiple researchers or volunteers collect and enter data can vary significantly (Prendergast et al. 1993). This is unfortunate but understandably cannot be rectified, for example not all projects collect the same data, circumstances can arise during studies causing surveys to be aborted, or people simply lack the time to enter all collected data to the database (Griffiths et al. 1999, Porter 2000). This inconsistency of data was found to cause difficulty in assessing which depth macroalgae were recorded in, with records providing an exact depth, a broad range (e.g., 1m-100m) or no information at all. For this reason, records were removed if found to be located more than a kilometre from land. This kilometre boundary was employed to help limit the occurrence data to the shallow subtidal zone, helping to ensure all records were from a similar habitat. It should also be noted that the data collected from Griffiths and Waller (2016) study, focussed only on intertidal assemblages, while data from GBIF (2019) and OBIS (2019) provide both intertidal and subtidal occurrences.

The addition of molecular data to diversity databases provides a more robust dataset, allowing for accurate identifications and easy amendments when taxonomic revision is required. This would also significantly increase the quality of data accessible, reducing the number of records that have only been recorded to family or other higher levels. With taxa identified to the lowest levels, biogeography studies could obtain better species inventories and occurrence data, therefore increasing sample effort and the quality of statistical testing.

Average taxonomic distinctness (AvTD or Δ+) has been employed in a variety of ecological investigations, such as nematode community colonisation after ice-scour (Raes et al. 2010), nutrient levels in freshwater ecosystems (Vilmi et al. 2016) and the importance of different coastal systems to early development of fish (Azevedo et al. 2017). These taxonomic indices have already been employed in similar studies to this one, such as the work by Ceschia et al. (2007) who used taxonomic distinctness to assess macroalgal diversity in the Gulf of Trieste. Taxonomic distinctness indices are useful in biogeography studies such as this as they are not dependent on sample size or effort (Clarke and Warwick 1998, Hu and Zhang 2016). This is evident in the results of this study where the AvTD of Chlorophytes was greatest in South Georgia, which had the lowest number of species and grids.

Although it is commonly assumed that Antarctica had complete ice cover during the LGM, evidence of survival of taxa during glaciation has been documented. Terrestrial fauna such as arthropods and freshwater algae have been shown to have lineages unique to the continent (De Wever et al. 2009 Fraser et al. 2012, Billard et al. 2015). However, in the case of marine flora, no such lineages have thus far been determined, with any macroalgae removed from the substratum by ice scouring in the LGM and recolonized by founder populations in South America and New Zealand (Fraser et al. 2010). Dispersal of brown algae would most likely have been from floating of buoyant pneumatocysts or thalli, with red and green macroalgae rafting on these buoyant floats (either as epiphytes or endophytes) (Macaya et al. 2016). Populations of *Durvillaea antarctica* and *Macrocystis pyrifera* - two important kelps in the shallow benthic environment - have already been found to be genetically identical throughout the sub-Antarctic (Fraser et al. 2009, 2010, 2012). Bull kelp D. antarctica has also been shown to withstand rafting events for dispersal and was known to be eradicated from rocky subtidal and intertidal regions of Antarctica during glaciation (Fraser et al. 2009). This study improves the knowledge of macroalgal biogeography in the South Atlantic, linking exposure since the last glaciation to species occurrences in the region. The use of DNA barcoding has not only enhanced the algal flora of the Falkland Islands, but also improved the knowledge of algal diversity in the broader region of the South Atlantic by documenting the first occurrence of *Pylaiella washingtoniensis* in the Southern hemisphere, which was previously thought to only have an Arctic and North Pacific distribution.

Image: *Patagonotothen brevicauda and Pseudechinus magellanicus*. Credit: SMSG.

1.3 INSHORE: SPATIAL PATTERNS AND ZONATION IN FALKLAND ISLANDS INTERTIDAL ECOSYSTEMS

This chapter is taken and adapted from PhD research undertaken by Dr Emma Beaton at SAERI/SMSG and the University of Aberdeen. Beaton, E. C. (2020). Shallow Benthic and Intertidal Ecology of the Falkland Islands. PhD Thesis, University of Aberdeen. pp 222.

ABSTRACT

This study details the first description of the influence of spatial scales on rocky intertidal invertebrate communities in the Falkland Islands. Surveys were conducted on 15 rocky shores around the Islands between Austral summer (January) 2016 and Austral autumn (April) 2018, recording 102,229 individuals from 28 taxa. The Lower shore was characterised by *Mytilus edulis* beds, barnacles and Magellanic copper limpet *Nacella magellanica*. The Middle shore was dominated by purple mussel *Perumytilus purpuratus*, along with pulmonate limpets belonging to the genera *Siphonaria* and *Lottia*. Spirorbid annelids characterised the Upper shore. The Upper and Lower shores were found to be most dissimilar, with the Middle shore occupying Upper and Lower shore taxa, acting as a transition between the two different communities. Exposure was found to be a greater influencing factor on community structure than steepness, likely due to increased wave action, allowing for the upwelling of nutrients and more protection from physiological stresses such as desiccation. In combined shore groups, exposed flat shores were found to be most diverse, followed by sheltered flat and finally sheltered steep displaying the lowest diversity. This is likely attributed to the narrowing of shore zones on steep shores, resulting in more competition for resources such as space and food availability.

INTRODUCTION

Little is known of the community structure of the intertidal region of the Falkland Islands, however studies of marine biodiversity have been undertaken since the 1800s. For example, in 1898-1899 work on hydroids provided one of the first robust studies into the intertidal fauna of the Islands, which previously had been limited to opportunistic collections by expedition ships (Browne 1902). However, the majority of intertidal research in the Falkland Islands has been carried out in Stanley Harbour (Browne 1902; van Tussenbroek 1989a, b, c, 1993; Waller 2008; Laptikhovsky et al. 2015) with a number of studies collecting invertebrate samples from the hull of the SS Great Britain (Monro 1936; Davenport et al. 1984) prior to its return to England in 1970 (Watkinson and Tanner 2008).

Outside of the Stanley area studies of intertidal taxa include: the reproductive development of blue mussel *Mytilus edulis* (Gray and Richardson 1997) and chitons and polychaetes around the Islands (Sirenko 2006; Darbyshire 2014). Gaps in knowledge of the Falklands intertidal zone have continued to be addressed in more recent years with Richardson (2015) studying faunal communities in *M. edulis* beds at three locations across East Falkland. However, with a coastline of 1288 km (Broom et al. 2010), and diurnal tides with a maximum range of 1.9 m (Laptikhovsky et al. 2015) these studies have only scratched the surface of possible research in the intertidal zone.

The Falkland Sound divides the two main Islands from the north-east to the south-west. This divide results in a cold-temperate environment in the west and a sub-Antarctic environment in the east of the Islands (Arkhipkin et al. 2013; Sabatini et al. 2016). The impact this has on the rocky intertidal fauna has never been thoroughly examined before, and Beaton et al. (2020) provide base-line vital knowledge on the fauna occupying the intertidal region around the Falklands, advancing knowledge of biogeographical patterns at a local scale. Specifically, the Beaton et al. (2020) study explored (1) how invertebrate communities change over small spatial scales from the lower to upper zone of the Falkland Islands' rocky shore and (2) changes in faunal community structure at large spatial scales.

Image: Feathered nudibranch *(Aeolidia papillosa) in the intertidal zone. Credit: Dr. S Carter.*

METHODS

Survey locations and quadrate protocol

Surveys were carried out at 15 sites around the Islands between during austral summer and autumn from December 2016 and April 2018. When possible, surveys were conducted during spring tides. A map of the site locations is displayed in Fig. 1.8.

At low tide, a transect was placed perpendicular to the water, stretching from the strandline to the water. Initially one transect per site was surveyed, however in July 2017 this methodology was expanded to four transects per site to allow for more quantitative data to be collected. This methodology was employed for the surveys at East Cove, Fox Bay West and Saunders Island. Three transects were surveyed at Carcass Island, due to a decline in weather conditions. To limit the influence of seasonal variation, surveys were carried out over Austral summer and autumn, with the exception of the Carcass Island surveys, which were carried out in Austral spring 2017. A quadrat was haphazardly placed along the transect on altering each side of the transect at 2 m intervals, although care was taken to avoid rockpools which made photo analysis difficult. Due to the length of the intertidal zone, the survey at Christmas Harbour had quadrats placed every 3 m to allow for the whole littoral zone to be surveyed during the low tide. Standardised forms were used to assess the substrate and survey area (JNCC 2014) and input into Marine Recorder software for future access.

Image analysis

Image analyses were completed using photoQuad software (Trygonis and Sini 2012), except quadrats which were dominated by barnacles or mussels, which were counted by hand. One hundred random points were used to assess the area cover of primary substrate and algae to provide a finer resolution for 'busy' quadrats with several different substrate types. If a point landed on fauna, the substrate under the animal was assigned. Functional groups were used to categorise algae and substrate categories followed those on the standardised sublittoral form (Table 1.6).

Table 1.6. Functional groups used for assessment of percent area cover

Chlorophyta	Rhodophyta	Ochrophyta
Green Corticated Foliose	Red Articulated Calcareous	Brown Corticated Foliose
Green Corticated Terete	Red Corticated Terete	Brown Corticated Terete
Green Filamentous	Red Crustose	Brown Filamentous
Green Foliose	Red Filamentous	Brown Foliose
Green Foliose (Fine)	Red Foliose	Brown Leathery
Green Saccate	Red Leathery	Brown Curled Foliose
		Brown Saccate
		Kelp

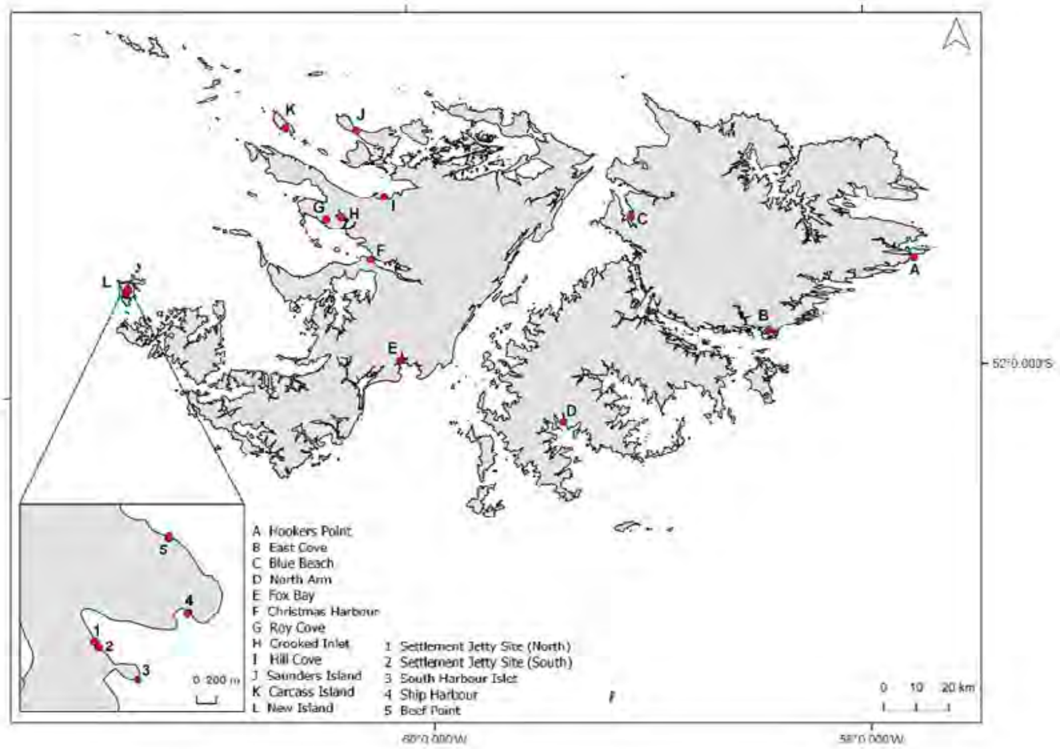

Fig. 1.8: Map of the Falkland Islands detailing intertidal field sites.

Data analysis

Species accumulation curves using the UGE (Ugland, Gray & Elingsen) estimator were produced using 9999 permutations (Ugland et al. 2003), in order to assess sampling effort based on faunal species occurrence (Cárdenas and Montiel 2015). Each site was split into upper, middle and lower shore zones to assess small spatial scales. Sites were categorised by beach direction, steepness and exposure to help identify patterns in community composition. Steepness was defined as 'steep' or 'flat', with 'steep' classified as displaying a moderate gradient and 'flat' displaying no visible slope. Exposure was defined as 'exposed' or 'sheltered', with 'exposed' classified as a shore open to the ocean and 'sheltered' describing sites within bays and inlets. Table 1.7 shows how each shore was categorised. Diversity indices were used to assess the richness (S), Pielou's evenness (J') and Shannon-Weiner diversity (H') of each community, with the Shannon-Weiner index calculated using log base e. Diversity indices were examined across the upper, middle and lower shore. Within each shore region factors were assessed individually, and as a combination of exposure and steepness: 'sheltered flat'; 'sheltered steep'; 'exposed flat'. No sites were identified as 'exposed steep'. Principal co-ordinate analysis (PCO) was carried out to identify differences in communities between the factors.

Table 1.7. Factors attributed to each survey site.

Site	Facing	Exposure	Steepness
Hookers Point	North East	Exposed	Flat
East Cove	South	Sheltered	Flat
Blue Beach	West	Sheltered	Flat
North Arm	East	Sheltered	Flat
Fox Bay	East	Sheltered	Flat
Christmas Harbour	North	Sheltered	Flat
Roy Cove	West	Sheltered	Steep
Crooked Inlet	North	Sheltered	Flat
Hill Cove	South	Sheltered	Steep
Carcass Island	South	Exposed	Flat
Neck, Saunders Island	North West	Exposed	Flat
New Island Jetty North	East	Sheltered	Steep
New Island Jetty South	East	Sheltered	Steep
South Harbour Islet	South West	Sheltered	Steep
Ship Harbour	South	Sheltered	Steep
Beef Point	North	Sheltered	Flat

Data were transformed using a fourth root transformation to down-weigh any influence of extremely abundant taxa and a Bray-Curtis resemblance matrix was created. Canonical analysis of principle coordinates (CAP) was performed using the factors as a *priori* groups to determine how well the sites had been categorised. The ten most abundant taxa across the surveys were superimposed onto the CAP graphs as vectors to assess the influence of each factor on the taxa. Analysis of similarities (ANOSIM) was employed to assess the extent of which communities between shore zones and between factors varied, with similarity profiles (SIMPER) to determine the taxa driving these variations. Redundancy analysis (RDA) was them carried out to determine the influence of substrate type on invertebrate species distribution using Brodgar (v2.7.5 2017). Univariate analyses were performed using GraphPad Prism (v8.2.0 2019), and multivariate analyses were run using PRIMER version 7.

Results

A total of 102,229 individuals comprising 28 taxa were recorded from 340 photo quadrats, representing an area of 85.25 m^2. Nine classes were identified during these surveys, the most dominant being Gastropoda which comprised 15 taxa. The number of individuals found per quadrat ranged from 0 to 6964, with an average of 285.3 individuals per quadrat. Of the 19 vagile taxa recorded, *Siphonaria lateralis* was the most abundant with a mean density of 36 individuals m^{-2}, with a range of 0 to 2512 ± 186.3 individuals m^{-2}. The most abundant sessile taxon was *Notochthamalus scabrosus*, with a mean density of 795 individuals m^{-2}, and a range of 0 to 27708 ± 2951.4 individuals m^{-2}.

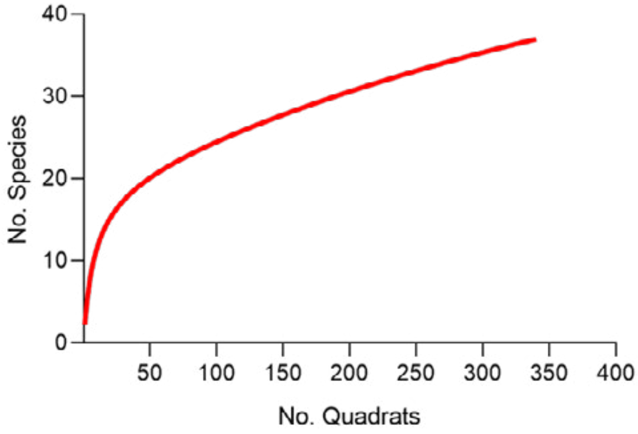

Fig. 1.9: *Species accumulation curve using the UGE estimator.*

The substrate cover of the Upper and Middle shore were dominated by bedrock, small boulders and cobbles, with low coverage and diversity of algae. The Upper shore was composed of 7% green foliose algae and the Middle shore exhibited 8% algal cover. The Lower shore was dominated by bedrock, cobbles and coarse sand, and exhibited high coverage of algae at 42%, comprising eight functional groups. Exposed shores exhibited a high coverage of bedrock (41%) in comparison to Sheltered sites which only showed a 14% cover of bedrock but greater coverage of cobbles (25%). Sheltered shores also displayed a lower coverage of algae, at 21% compared to the 33% cover on Exposed shores. Flat shores were made up of bedrock (28%) and cobble (15%), while Steep shores composed of cobbles and small boulders (26% and 23% coverage respectively). Algal coverage was slightly higher on Flat sites compared with steep sites, with a coverage of 27% and 21% respectively. On all shores, Green foliose was the most abundant algal functional group.

The species accumulation curve in Fig. 1.9 does not reach an asymptote, indicating that more taxa were present than those recorded in the surveys. Saunders exhibited the greatest total number of species and Ship Harbour displayed the lowest, with values of 15 and 4, respectively. Evenness (J') was highest in North Arm (0.769) and Roy Cove (0.752), and lowest in Christmas Harbour (0.023), as displayed in Table 1.8. Roy Cove also displayed the highest diversity (H') along with Fox Bay, with values of 1.645 and 1.615, respectively. Christmas Harbour again exhibited the lowest diversity, with a value of 0.052.

Table 1.8. Diversity measures for each survey site.

Site	S	H' (log e)	J'
Hookers Point	6	0.927	0.517
East Cove	6	1.197	0.668
Blue Beach	10	1.098	0.477
North Arm	8	1.599	0.769
Fox Bay	15	1.615	0.596
Christmas Harbour	9	0.052	0.023
Roy Cove	9	1.654	0.753
Crooked Inlet	8	0.565	0.271
Hill Cove	5	1.072	0.666
Saunders Island	16	0.676	0.235
Carcass Island	10	0.998	0.433
New Island Jetty North	6	0.603	0.336
New Island Jetty South	7	0.936	0.481
South Harbour Islet	9	0.136	0.062
Ship Harbour	4	0.293	0.212
Beef Point	7	0.764	0.392

Fig. 1.10 shows a comparison of diversity indices for each factor separated by upper, middle and lower shore. Exposed shores exhibited the greatest H' in the upper shore (0.365), which is also the highest H' across all factors and shore regions. In the middle shore, sheltered and flat shores displayed the greatest H', both with values of 0.331. Steep shores exhibited the lowest H' in the upper and middle shores, with values of 0.193 and 0.287 respectively. In the lower shore, exposed shores displayed the lowest H' with a value of 0.076.

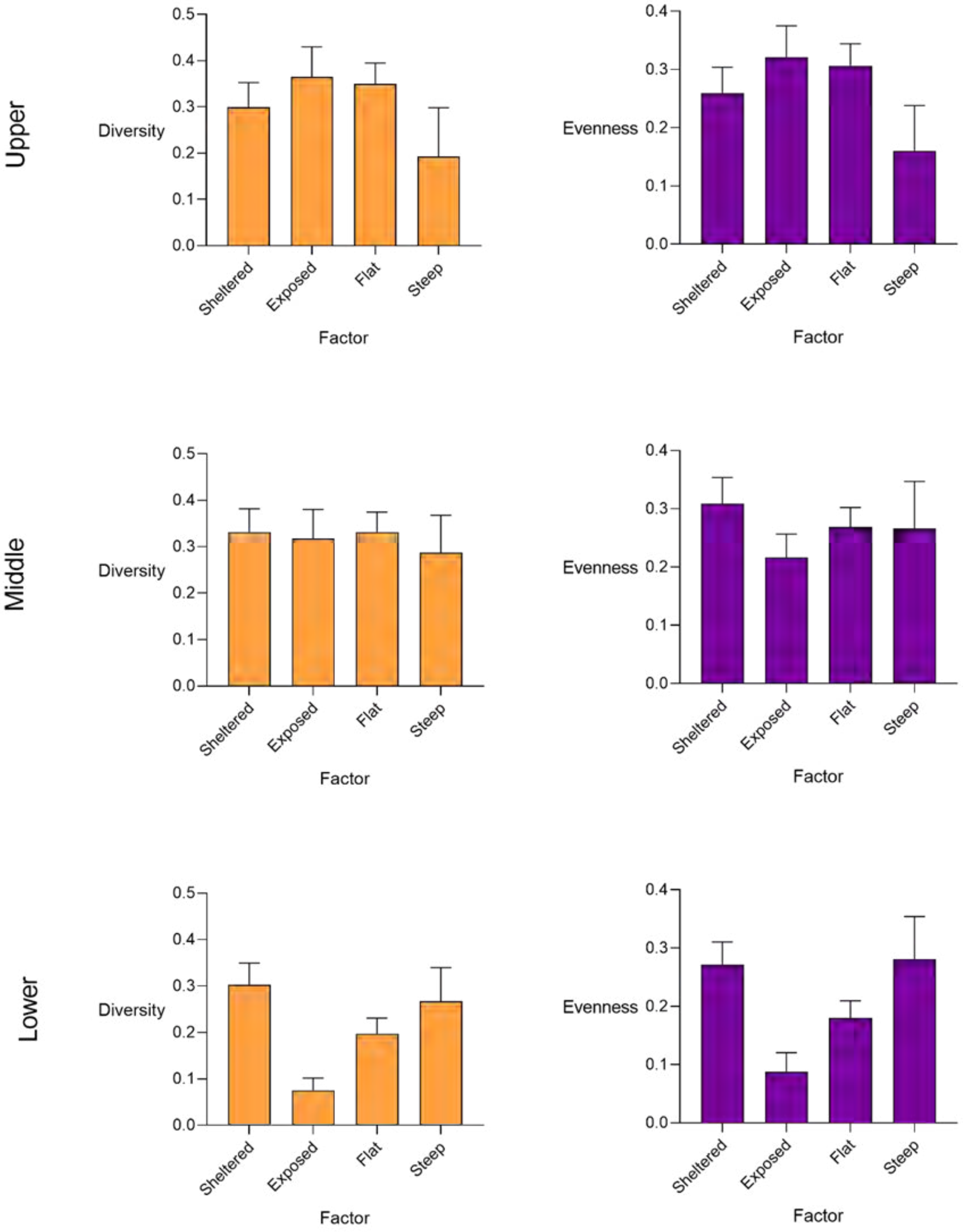

Fig. 1.10: *Diversity measures of each factor separated by shore zone, with error bars displaying standard error of the mean.*

J' was greatest in exposed shores in the upper region (0.321), sheltered shores in the middle region (0.309) and steep shores in the lowest shore region (0.281). In the upper shore, the lowest J' value was displayed in steep shores, with a value of 0.160. Exposed shores exhibited the lowest J' in the middle and lower shores, with values of 0.216 and 0.088 respectively.

Fig. 1.11 shows the comparison of diversity measures against combined factors. The greatest H' was shown in steep flat shores in the upper regions of the shore (0.365), whereas sheltered flat shores exhibited the greatest H' in the middle and lower shores (0.345 and 0.314 respectively). Sheltered exposed shores showed the lowest H' in the upper and middle regions (0.193 and 0.287 respectively), with steep flat shores exhibiting the lowest H' in lower regions (0.076). The greatest J' was displayed in the steep flat sites in the upper shore (0.321), sheltered flat in the middle shores (0.281) and sheltered exposed sites in the lower shore (0.281). Steep flat shores displayed the lowest J' in the upper shore, with a value of 0.160, whereas steep flat sites exhibited the lowest J' in middle and lower shores (0.225 and 0.088 respectively).

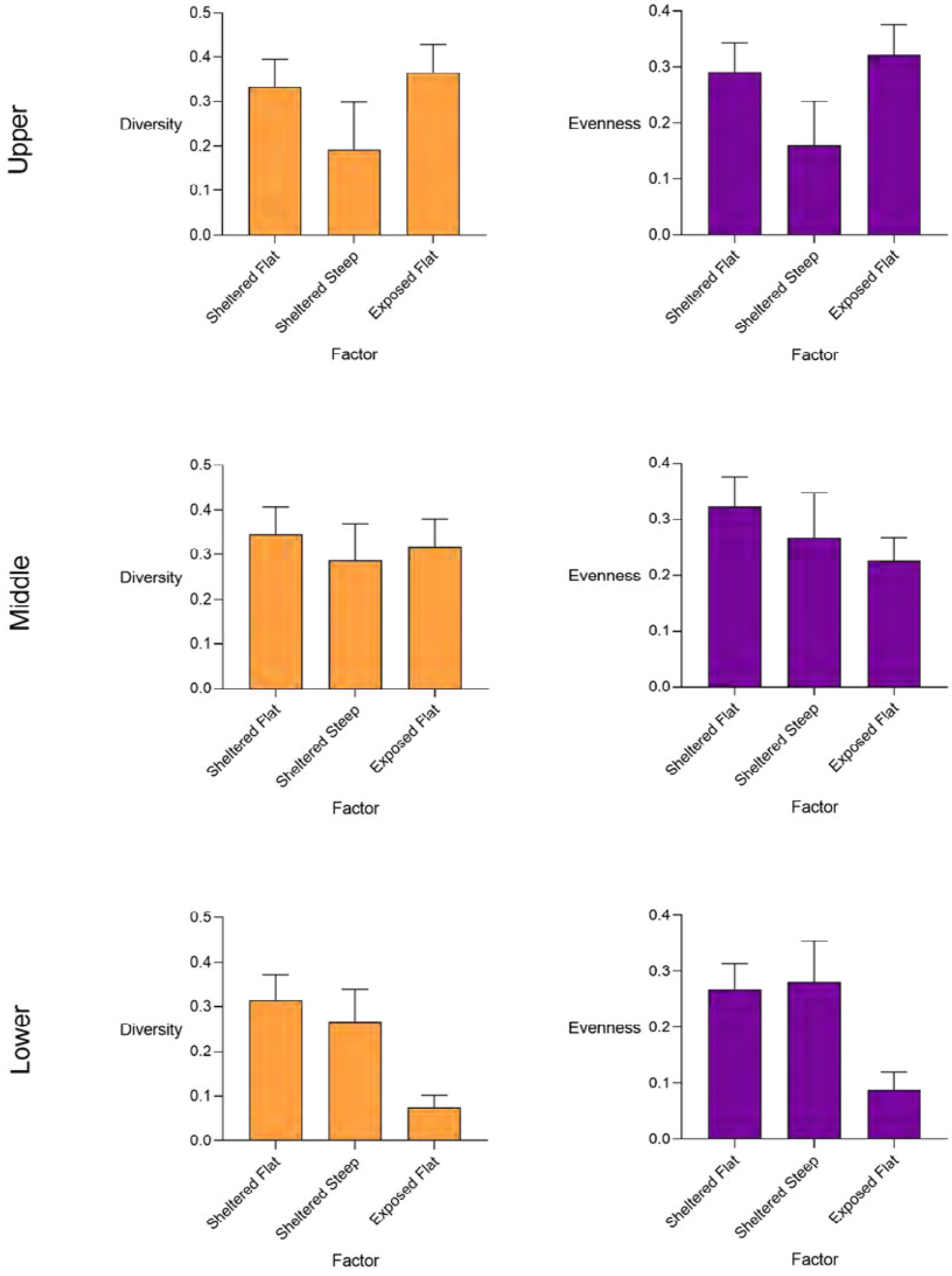

Fig. 1.11: Diversity measures of combined factors separated by shore zones, with error bars displaying standard error of the mean.

Spirorbid annelids appear to be driving the community in the Upper shore, as shown in the PCO plot of the combined sites in Fig. 1.12. In the Middle shore, limpets *Siphonaria* sp., S. lateralis and *Lottia* sp. as well as purple mussels *Perumytilus purpuratus* were influencing the Middle shore. Barnacles *Notochthamalus scabrosus* and *Elminius kingii* and bivalve *Mytilus edulis* were found to be driving the community structure of the Lower shore. PCO between combined factors shows a clear distinction between the Lower shore and the overlapping Middle and Upper shores in the 'exposed flat' sites. No discernible pattern was observed between shore regions within the 'sheltered flat' and 'sheltered steep' groups, as displayed in Fig. 1.13, between the communities of the shore regions.

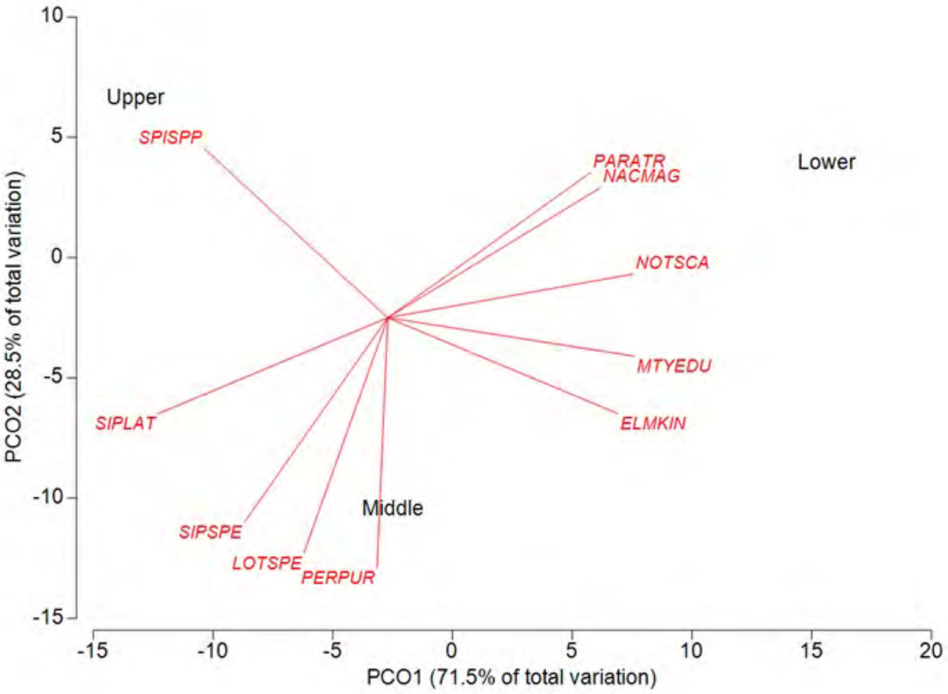

Fig. 1.12: *PCO showing the species driving change to community structure in the upper, middle and lower shores (where ELMKIN= Elminius kingii, LOTSPE= Lottia sp., MYTEDU= Mytilus edulis, NACMAG= Nacella magellanica, NOTSCA= Notochthamalus scabrosus, PARATR=Pareuthria atrata, PERPUR= Perumytilus purpuratus, SIPLAT= Siphonaria lateralis, SIPSPE= Siphonaria sp., SPISPP= Spirorbinae.*

Image: *Actinostola chilensis*. Credit: SMSG.

Spirorbid annelids appear to be driving the community in the Upper shore, as shown in the PCO plot of the combined sites in Fig. 1.12. In the Middle shore, limpets *Siphonaria* sp., *S. lateralis* and *Lottia* sp. as well as purple mussels *Perumytilus purpuratus* were influencing the Middle shore. Barnacles *Notochthamalus scabrosus* and *Elminius kingii* and bivalve *Mytilus edulis* were found to be driving the community structure of the Lower shore. PCO between combined factors shows a clear distinction between the Lower shore and the overlapping Middle and Upper shores in the 'exposed flat' sites. No discernible pattern was observed between shore regions within the 'sheltered flat' and 'sheltered steep' groups, as displayed in Fig. 1.13, between the communities of the shore regions.

The CAP analysis achieved a high level of success in classifying quadrats in the Upper and Lower shore. However, the classification of Middle quadrats was very poor as shown in Table 1.9. The graph in Fig. 1.14 shows overlap of Middle points across the graph. A divide can be observed in the Upper points on the left-hand side and Lower points on the right-hand side of the plot, with a small overlap of points in the centre of the graph. CAP also achieved success in classifying factors 'Steepness' (72% and 66% correctly classified as 'flat' and 'steep' respectively) and 'Exposure' (71% and 77% correctly classified as 'sheltered' and 'exposed' respectively).

Table 1.9. Classification of a *priori* groups by CAP.

Original Groups	Upper	Middle	Lower	% Correct
Upper	42	15	19	55.263
Middle	43	20	31	21.277
Lower	17	14	62	66.667
	Exposed	Sheltered		% Correct
Exposed	27	91		77.119
Sheltered	103	42		71.034
	Flat	Steep		% Correct
Flat	166	65		71.861
Steep	11	21		65.625

Image: *Antholoba achates*. Credit: SMSG.

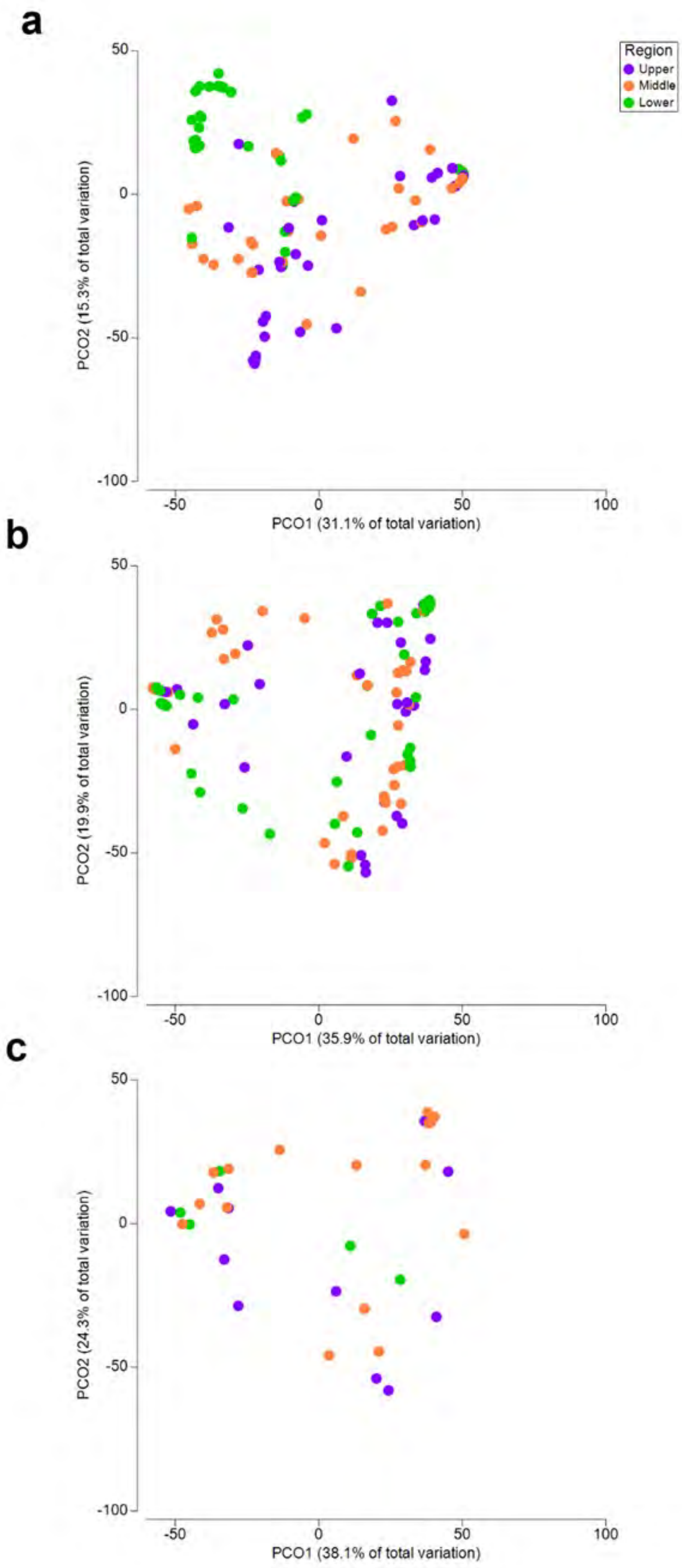

Fig. 1.13: *PCO analysis of a exposed flat shores b sheltered flat shores c sheltered steep shores.*

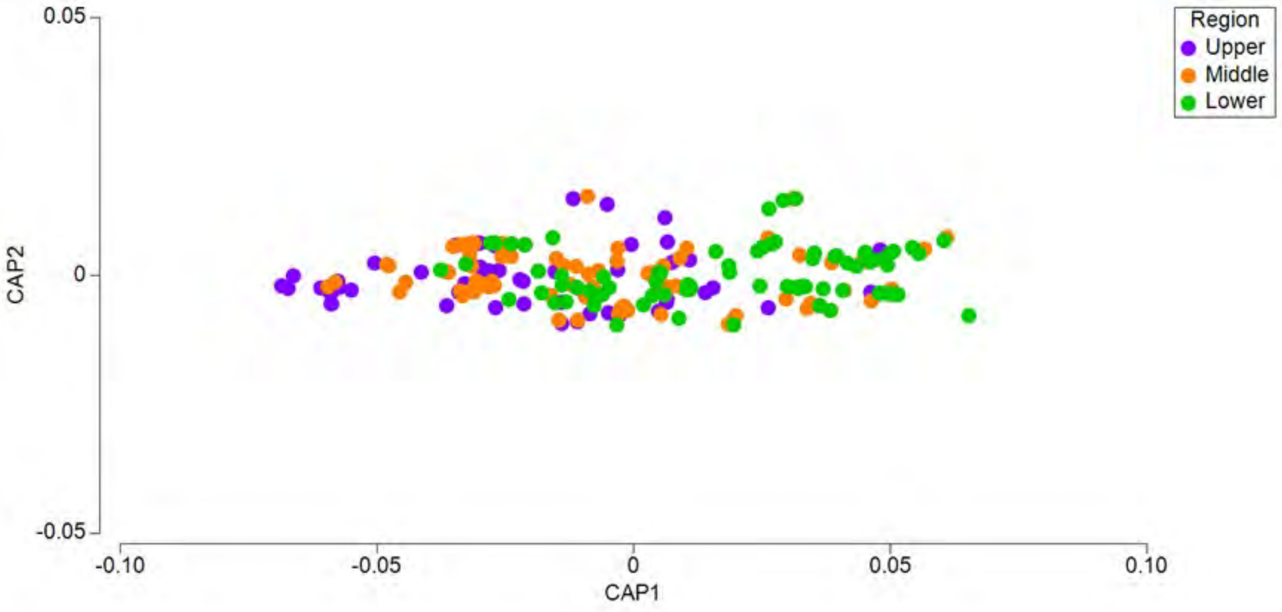

Fig. 1.14: *CAP plot separating intertidal faunal communities by shore zones.*

ANOSIM of the combined counts found that Lower vs. Upper shores were most dissimilar with an R value of 0.068 (*P*=0.1%), whereas Middle vs. Upper shores were found to be most similar (R= 0.008, *P*=9.3%) as displayed in Table 1.10. SIMPER determined that *N. scabrosus* was the most influential in the community structure between Lower vs. Middle and Lower vs. Upper shores, contributing to 23.16% and 22.87% of community variation, respectively). *P. purpuratus* was the taxa found to contribute most in the variation of communities between the Middle vs. Upper shores, contributing 23.29% to the changes in community structure. Exposure was found to have a greater influence on community structure than steepness, with an R value of 0.054 (*P*=0.1%) between exposed vs. sheltered shores compared to an R value of. 0.022 (*P*=25.1%) between flat vs. steep sites. However, *N. scabrosus* was found to be the driver of changes in the community composition between both flat vs. steep and exposed vs. sheltered sites (contributing 24.20% and 20.89% to variation in communities restrictively).

The RDA plot in Fig. 1.15 shows coarse sand to be a strong influence on *Mytilus edulis* communities, whereas *Nacella deaurata* and Isopod sp. 1 showed a negative correlation. Bedrock was found to be positively correlated with *Siphonaria lateralis* and to a lesser extent with *N. scabrosus*, *E. kingii*, *Lottia* sp. and *P. purpuratus*. *Pareuthria atrata* and *Pareuthria* sp. were influenced by red foliose algae, while *Onchidella* sp. *Pyura chilensis* were correlated with green foliose algae. Spirorbid annelids were found to be positively correlated with cobbles and pebbles but were found not to be influenced by bedrock.

Table 1.10. Ordered pairwise ANOSIM comparisons, of three zones, between benthic assemblages.

Group	R	*P*
Lower, Middle	0.037	0.1%
Lower, Upper	0.068	0.1%
Middle, Upper	0.008	9.3%

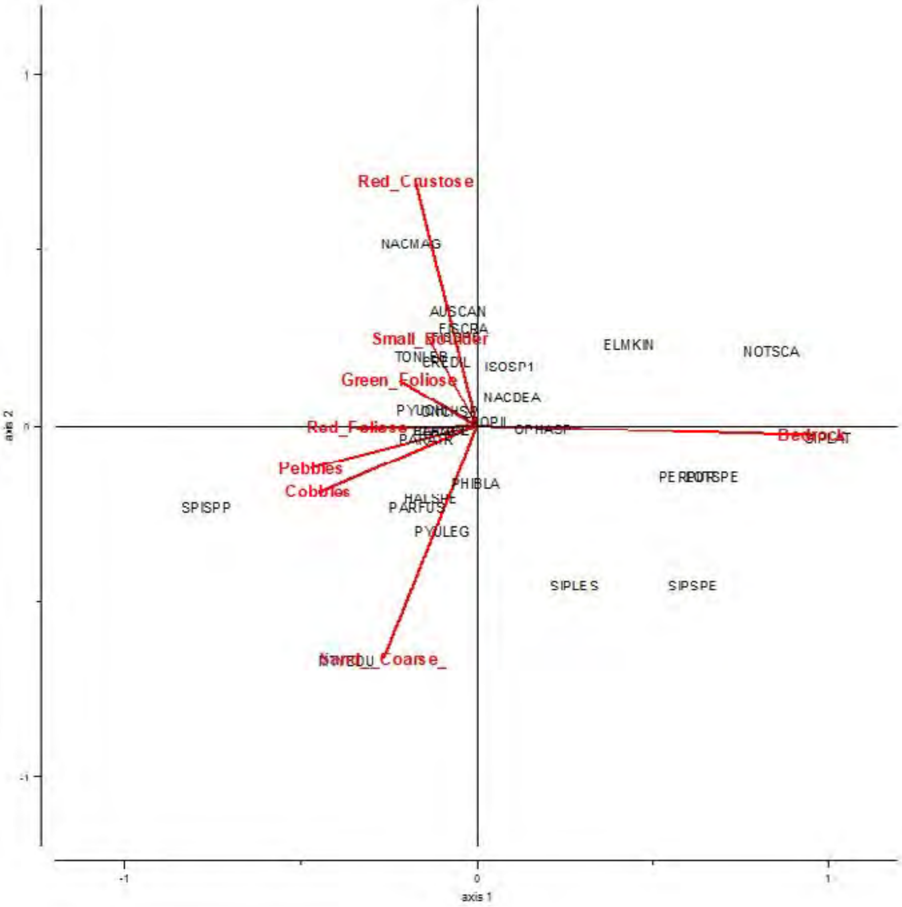

Fig. 1.15: *RDA plots with substrate type factors influencing community structure (AUSCAN:* Austrocidaris canaliculata, *BLAMOL:* Laevilitorina caliginosa, *CREDIL:* Crepipatella dilatate, *ELMKIN:* Elminius kingii, *FISCRA:* Fissurella crassa, *HALSPE:* Haliclona *sp, ISOSP1:* Isopod *sp. 1, LOTSPE:* Lottia *sp., MYTEDU:* Mytilus edulis, *NACDEA:* Nacella deaurata, *NACMAG:* Nacella magellanica, *NOTSCA:* Notochthamalus scabrosus, *ONCHSP:* Onchidella *sp., OPHASP:* Ophiactis asperula, *PARATR:* Pareuthria atrat*a, PARFUS:* Pareuthria fuscata, *PARSPE:* Pareuthria *sp., PERPUR:* Perumytilus purpuratus, *PHIBLA:* Philobrya blakeana, *PYUCHI:* Pyura chilensis, *PYULEG:* Pyura legumen, *SIPLAT:* Siphonaria lateralis, *SIPLES:* Siphonaria lessoni, *SIPSPE:* Siphonaria *sp., SPISPP:* Spirorbinae, *TONLEB: T*onicia lebruni, *TROPIL: T*rochita pileolus*).*

Discussion

The Beaton study provides the first description of how invertebrate faunal communities inhabiting rocky intertidal zones in the Falkland Islands vary over spatial scales.

The total number of taxa (S) recorded in this study, 28, matches the number of taxa recorded at two of the three intertidal survey sites studied by Waller (2008) in the Falklands. This is a greater diversity than exhibited in the Strait of Magellan (Ríos and Gerdes 1997; Newcombe and Cardenas 2011). Waller's (2008) findings showed the Falklands intertidal faunal communities to be more similar to the Antarctic Peninsula than to the littoral communities of South America. This result was also found by Barnes and Lehane (2001), who determined that richness and evenness were greater in the Falkland Islands than in Patagonia and Tierra del Fuego, when examining sessile encrusting intertidal fauna. Barnes and Lehane (2001) also found that the encrusting invertebrate communities on the East Falkland shore showed a greater diversity and evenness than the West Falkland site. However, this study determined that the greatest faunal diversity was found in the north-west of the Islands. The greatest diversity (H') was exhibited at Roy Cove and greatest evenness (J') was found at North Arm, which were similar to the greatest diversity and evenness values determined by Ríos and Mutschke (1999).

The Upper shore is categorised by a high density of Spirorbid annelids. The Middle shore was dominated by limpets *Lottia* sp. and false limpets *Siphonaria lateralis* and *Siphonaria* sp. Members so the genus *Siphonaria*, first described in the Falkland Islands by Blainville in 1827 (Güller et al. 2016), are known to inhabit the mid- to low intertidal zone as they are air-breathing (Capon and Faulkner 1984; Tablado and López Gappa 2001; Simone and Seabra 2017). *Siphonaria* are mostly herbivorous feeders, with a diet of mainly green foliose micro- and macroalgae, such as *Enteromorpha* and *Ulva* (Godoy and Moreno 1989; Tablado and López Gappa 2001), which restricts their distribution from extending to the Upper intertidal. Mytlid *Perumytlius purpuratus* also occupies the Middle shore and is found in the Lower shore in smaller densities, where *Mytilus edulis* is in greater abundance. This distribution pattern follows the patterns found on mainland South America (Bertness et al. 2006; Adami et al. 2018). The distribution of *P. purpuratus* in the middle zone may allow for protection from predation. Sea star *Anasterias antarctica* is a known predator of *P. purpuratus*, however the sea star most likely partakes in opportunistic predation, taking advantage of mussels that become dislodged and fall into crevices and under boulders (Gil and Zaixso 2008). Other known predators of the bivalve include kelp gulls (*Larus dominicanus*), oystercatchers (*Haematopus ater* and *Haemotopus leucopodus*) (Adami et al. 2018) and striated caracara *Phalcoboenus australis* (pers. obs.). The Lower shore is dominated by barnacles *Notochthamalus scabrosus* and bivalve *Mytilus edulis* (Cuevas et al. 2006, López et al. 2010). *M. edulis* is known to extensively inhabit the middle and lower zones of the intertidal regions of the Falkland Islands and Southern South America (Gray et al. 1997, Gray and Richardson 1997; Ingólfsson 2005).

There was greater diversity and evenness in the exposed shores in the upper shore zone, followed by flat shores. Increased wave action on the exposed sites would allow waves to wash higher up the shore more frequently, allowing taxa to be immersed in water more frequently than on the upper limits of a sheltered shore. This more frequent contact with the waves may reduce the exposure to physiological stresses such as temperature and desiccation (Dayton 1971; Davenport and Davenport 2005). Furthermore, retreating higher up the shore on exposed shores would offer intertidal assemblages protection from dislodgement by wave action. There was a small difference between the diversity between factors in the Middle shore but much lower evenness on the exposed shores in comparison to the other shore types. This may be due to increased disturbance from waves dislodging species from the substrate. Diversity and evenness were lowest in the Lower shore at exposed sites where taxa would be most frequently subjected to high-energy waves and risk of dislodgement would be greatest (McQuaid and Lindsay 2005). Increased wave action has been linked to foraging behaviour in gastropod grazers (Rilov et al. 2005). It has been suggested that nocturnal foragers, such as *Fissurella crassa* (Aguilera and Navarrete 2011), feed at night when seas are generally calmer and thus limiting the risk of being dislodged (Rilov et al. 2005). Disturbance can also explain the high diversity and evenness in the Lower shore on sheltered sites, where wave energy is reduced. Steep shores also displayed a high diversity and evenness in the Lower zone, which is likely due to taxa crowing in the lower shore for food availability protection against desiccation (Dayton 1971).

In the combined shore groups, exposed flat shores exhibited the greatest diversity and evenness in the Upper shore, with the lowest indices displayed in sheltered steep shores. This is likely due to the exposed flat shores having more space for taxa to spread out, allowing for a more equal abundance and may reduce competition between species for food and spacing, creating a greater diversity. As previously discussed, the exposed shore provides greater food availability from upwelling cold waters (Pulgar et al. 2013) to the coast and reduces the exposure to physiological stresses from more frequent wave action submerging taxa. In the Middle and Lower shore zones, sheltered flat sites displayed the greatest diversity, with exposed flat sites reduced in the Middle shore and lowest of all in the Lower shore. This can be linked to the wave energy being most intense on the Lower shore and decreases moving up the Middle and Upper zones. This would result in a high risk of dislodgement from the wave impact, and also increase the ability of vagile taxa to move between the inter- and subtidal zones.

PCO displayed a clear distinction between Lower shore communities from Upper and Middle shores in the exposed flat sites. No clear patterns were observed in the sheltered flat or steep flat sites, further suggesting that exposure has a greater influence on rocky intertidal community structure. Spirorbid annelids were found to influence the community structure in the Upper shore, likely as a result of greater free space on rock surfaces in comparison to the Middle and Lower shores. The Middle shore community is most influenced by the pulmonate limpets and *P. purpuratus*, while *M. edulis* and barnacles are of greatest influence in the Lower shore, likely due to the upwelling of cool waters washing up the lower intertidal providing nutrients to these filter-feeding taxa (Seed and Suchanek 1992).

The classification of quadrats in the CAP analysis shows a low success in assigning Middle quadrats to the correct group. This result, along with the high success rate in classifying Upper and Lower quadrats suggests that the Middle shore is a transitional zone between the calm Upper and disturbed Lower limits of the shore, with a high degree of overlap with these two regions, causing the Middle shore to be difficult to distinguish. The results of the ANOSIM also support this view, with low R values in Lower vs. Middle and Upper vs. Middle comparisons. SIMPER determined that exposure was a greater influence on faunal community structure than steepness. This may be because exposure influences a number of factors, thermal stress, desiccation, nutrient availability, risk of dislodgement, whereas steepness influences competition for space and food (Connel 1972; Menge and Olson 1990; Dahlhoff et al. 2001).

RDA found a strong correlation between coarse sand and blue mussel *M. edulis*. This is likely a result of sand being washed up shore and settling in the mussel beds. *Pyura legumen* was also influenced by coarse sand, in which individuals were observed partially buried in the intertidal site at Fox Bay (Beaton per obs). In contrast, *Pyura chilensis* was found to be influenced by green foliose algae. It has previously been documented that the solitary ascidian is often encrusted with algae, with only the red siphons visible (Neely and Brickle 2013). This was also found to be the case in this study, where *P. chilensis* was recorded within patches of *Codium fragile* and *Ulva* sp. (pers. obs.) and encrusted with algae. Green foliose was also found to be positively correlated

with *Onchidella* sp., while *Pareuthria atrata* and *Pareuthria* sp. and *Laevilitorina caliginosa* were positively influenced by red foliose algae. *Onchidella* sp. are known to graze on algae (Luckens 1974; Alfaro 2009), whereas *Pareuthria* sp. feed on detritus (Adami and Gordillo 1999) and likely occupy feeding grounds of grazers where there would be a greater availability if detritus matter. Spirorbid annelids were found to be negatively correlated with boulder and bedrock, instead showing a correlation with cobbles and pebbles. This may be due to competition with limpets and barnacles for space in substrate, therefore favouring smaller rock surfaces.
A number of limitations are recognised within the study. The survey methodology was improved upon in July 2017, increasing the number of transects per survey from one to four (with the exception of the Carcass Island survey in which poor light prevented the completion of a fourth transect). In order to maximise the quantity of data in the investigation, the original one-transect surveys remained in the dataset. This has resulted in a lack of standardisation in the methodology. In addition, due to the limited time at each site, the surveys collected quadrat photos only on the surface of each transect. This will have resulted in invertebrates who occupy the under-boulder region of the shore to be missed during surveys. This is reflected in the species accumulation curve which does not reach an asymptote. Limitations in use of quadrat photography is described by Foster et al. (1991), Preskitt et al. (2004) and Bowden (2005). A broader range of gradient and exposure from a greater number of shores would allow for the influences of these factors to be more closely examined. Future work should also explore the effect of more environmental factors such as desiccation and temperature on the distribution of intertidal invertebrate communities. *N. scabrosus* is known to inhabit upper regions of the intertidal zone in central Chile, which may be a result of warmer conditions allowing the barnacles to tolerate higher regions (Lamb et al. 2014).

This study provides the first description of rocky intertidal zonation around the Falkland Islands and how marine invertebrate communities vary across sites, identifying the greatest diversity in the north-west of the Islands and south-facing shores exhibiting lowest diversity. The results of this study suggest that exposure is a greater influence than steepness on the diversity and community structure, likely due to increased wave energy creating a more perturbed environment. This contributes important knowledge on biogeographical patterns for the Falkland Islands and southern South America.

Image: *Loxechinus albus* urchins and brooding brittle star *Ophiacantha vivipara*. Credit: SMSG.

1.4 INSHORE: THE INFLUENCE OF BATHYMETRY AND SEASON ON FAUNAL COMMUNITIES AROUND KIDNEY ISLAND

This chapter is taken and adapted from PhD research undertaken by Dr Emma Beaton at SAERI, SMSG and the University of Aberdeen. Beaton, E. C. (2020). Shallow Benthic and Intertidal Ecology of the Falkland Islands. PhD Thesis, University of Aberdeen. pp 222.

ABSTRACT

The section describes the Influence of depth and season on the benthic faunal communities of a *Macrocystis pyrifera* (giant kelp) forest at the iconic Kidney Island. It is significant, because information on the ecology of invertebrate communities populating *Macrocystis pyrifera* forests in the Falkland Islands are scarce. Indeed, factors influencing diversity, distribution and community structure are poorly understood. Therefore, this research provides important baseline information on giant kelp communities. Benthic photo quadrats were collected along permanent 20 m transects at three depths (5 m-10 m, 10 m-15 m, 15 m-20 m) off the coast of Kidney Island from Austral summer 2009 to Austral spring 2010. 146 taxa comprising 10 phyla and 21 classes were recorded during the surveys, with the most abundant sessile and vagile species being Spirorbid worms and the hermit crab *Pagurus comptus*, respectively. Bathymetric changes impacted the community structure as a whole, with highest species richness in the middle depths, and strong contrasts between shallow and deep communities. Influence of season on community structure was evident, though not as strong a factor as depth. Spring and summer months were most species rich, demonstrating a difference between the shallow subtidal regions of Patagonia where species richness was reported to be highest in austral autumn and winter. Percentage cover of Bedrock was determined to be a strong explanatory factor for a number of taxa, with *P. comptus* most correlated to depth. This study provides the first quantitative report on the benthic fauna and flora of shallow rocky reefs in the Falklands, describing how these communities change in small spatial and temporal scales. The outcomes of this investigation are an important contribution to better understanding ecological patterns of the Falklands shallow benthic environments and adds knowledge to the biogeography of the South Atlantic.

Image: Tiger featherduster (*Perkinsiana magalhaensis*) between the colonial sea squirt (*Distaplia* sp.). *Credit SMSG.*

INTRODUCTION

Kelp forests form important coastal habitats that harbour diverse benthic assemblages, with some taxa having evolved to specifically adapt to this habitat (Estes and Steinberg 1988; Hoshijima and Hoffmann 2019). Not only are kelp forests vital shelter for several species, but they are an important food source for many grazing taxa such as sea urchins, crustaceans and herbivorous fish (Dayton 1985). Changes to kelp forests' physical and/or community structures can have a significant impact on their surrounding environments (Küpper and Kamenos 2018). The canopy can affect water flow and, by reducing wave action, protect against coastal erosion (Smith and Bayliss-Smith 1998). The kelp canopy also prevents light penetration which provides a suitable habitat for many understory animals (Steneck et al. 2002) and limits competition between macroalgal species, which can influence recruitment of many benthic species (Duggins et al. 1990).

During the Last Glacial Maximum (~23 to 18 ka), the Falkland Islands likely provided refugia between the glaciated regions of Patagonia and South Georgia (Leese et al. 2008; González-Wevar et al. 2012). This may have led to recolonization in these areas from the stable 'founder' populations in the Falkland Islands.

Unpublished work has been carried out by the Shallow Marine Surveys Group (SMSG), who have been performing surveys and regular monitoring of sites around the Falklands since its conception in 2006 (Neely 2008 unpubl. data; Neely 2009 unpubl. data; Goodwin et al. 2011; Brickle et al. 2012 unpubl. data; Goodwin et al. 2016; Darbyshire and Brewin 2015; Figuerola et al. 2017).

This study provides the first quantitative description of benthic faunal communities of the Falkland Islands. Through the collection of data across spatial and temporal scales, this investigation aims to address the following questions: (i) How do small changes in bathymetry influence rocky reef invertebrate communities? (ii) What are the seasonal patterns of the benthic fauna community structure? This study aims to increase the understanding of regional biogeography in the Patagonian Shelf region of the South Atlantic.

METHODS

Study site

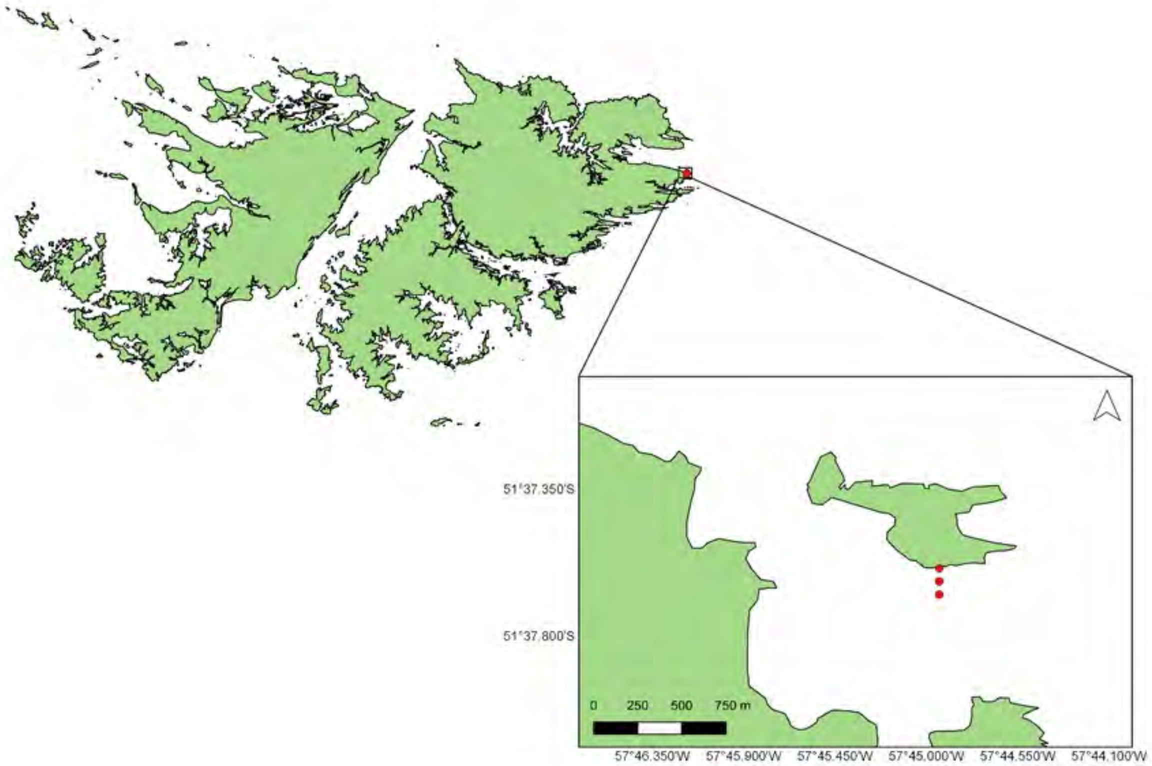

Fig. 1.16: *Map of the Falkland Islands and locations of permanent transects at Kidney Island*

Survey methodology

All surveys were conducted along permanent 20 m transects set at three depths, perpendicular to the shore (Fig. 1.16). Quadrat surveys were carried out using SCUBA by the SMSG. 0.25 m2 quadrats were placed on the sea floor every one metre along the transect on alternating sides (Fig. 1.17), and photographs of each quadrat were collected. Invertebrate species (≥20 mm) located within 1m on either side of the transect were counted, along with kelp stipe densities within the same area. *Macrocystis pyrifera* was identified to species level, however Lessonia spp. was identified only to genus as the taxonomy of this genus requires revision (Martin 2011; González et al. 2012). One survey was conducted at each of the three different depth ranges; shallow (5 m-10 m); middle (10 m-15 m); deep (15 m-20 m), every quarter over a two-year period from Austral summer 2009 to Austral spring 2010. Standardised forms for assessing sublittoral habitats were completed for each transect to record substrate data such as composition, inclination, rock features and sediment type, and the data was input into a Marine Recorder Database (JNCC 2014).

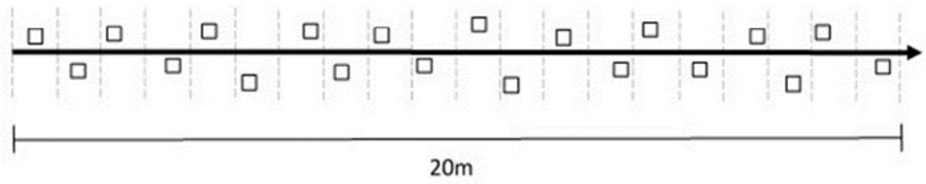

Fig. 1.17: *Placement of quadrats along transects*

Image Analyses

Photoquadrats were edited using Picasa (v3.9.141 2015) in order to straighten, sharpen and, if necessary, brighten and add contrast to the quadrat photos. Photos were screened for the best ten in each stratum to be used in the analysis. The software photoQuad v1.4 (Trygonis and Sini 2012) was used to count each individual invertebrate within the quadrats by placing markers on each individual (Fig. 1.18). Distinct sessile colonies were each counted as one individual and taxa were identified morphologically to the lowest possible taxonomic level. Five randomly selected photoquadrats from each stratum were used for percentage cover analysis. A Kruskal-Wallis test using fifty, one hundred or one hundred and fifty random points showed no significant statistical differences in percent area cover estimates (H= 3.919, P= 0.864). One hundred random points were used to assess the area cover of primary substrate and algae to provide a finer resolution for 'busy' quadrats with several different substrate types (Fig. 1.19). If a point landed on fauna, the substrate under the animal was assigned. All algae were categorised by functional group for the purpose of this analysis (Table 1.11) and substrate categories followed those on the standardised sublittoral form.

Image: *Actinostola chilensis.* Credit SMSG.

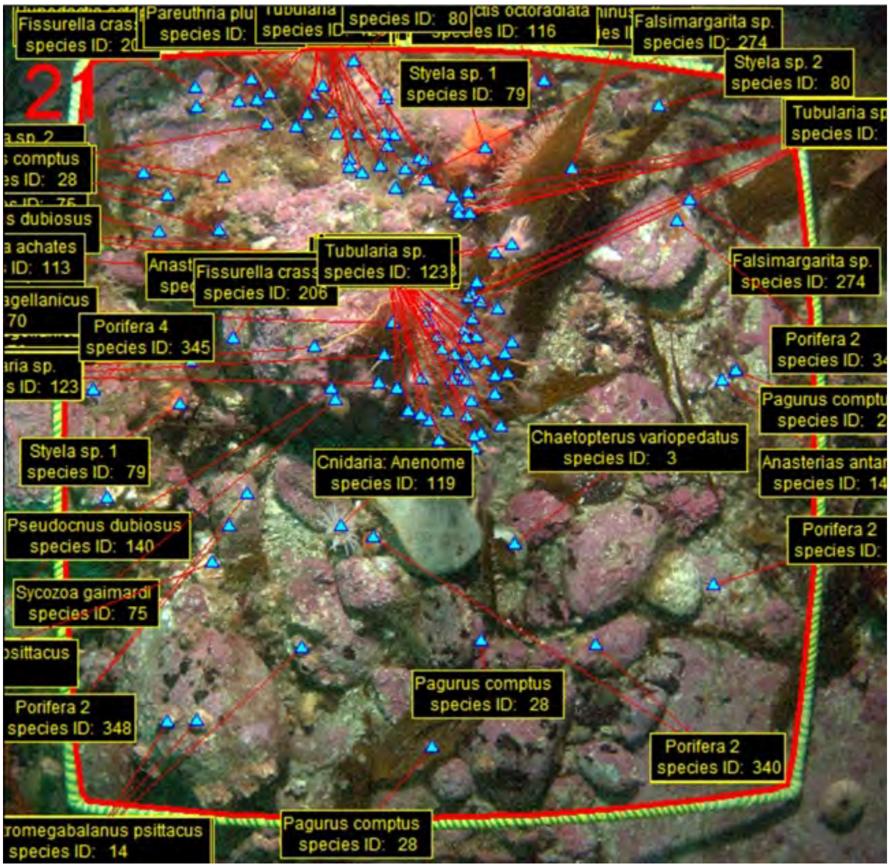

Fig. 1.18: *Example of photoquadrat analysed for species distribution. Photograph collected by SMSG.*

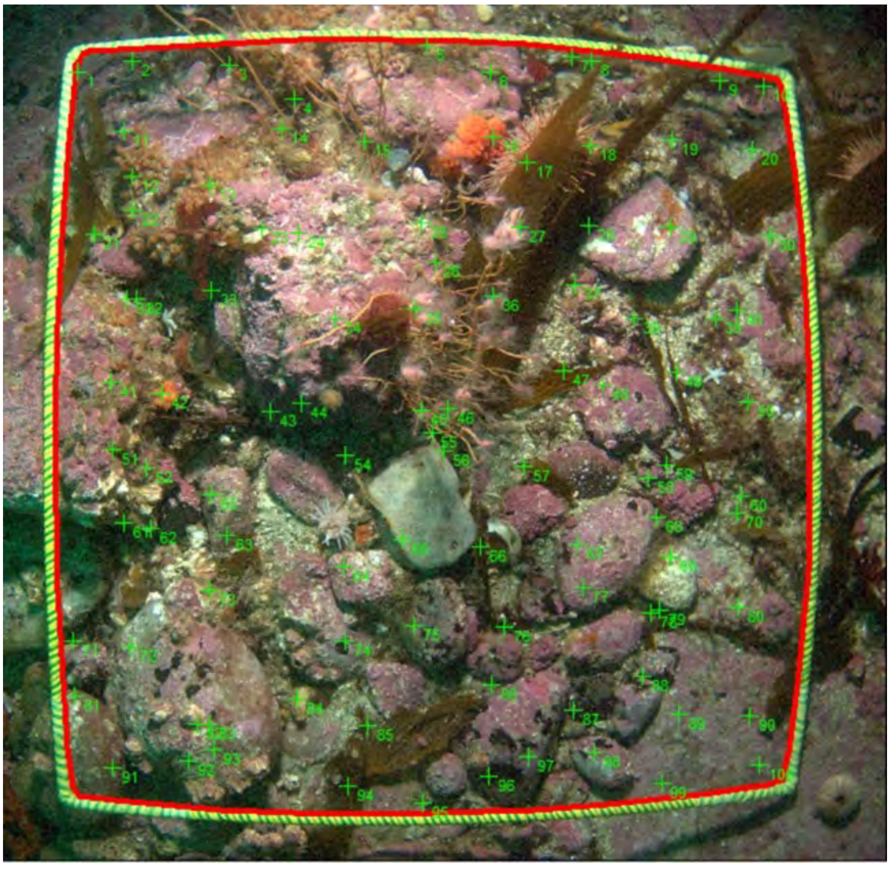

Fig. 1.19: *Example of photoquadrat analysed for percent area cover with 100 random points. Photograph collected by SMSG.*

Table 1.11. Algal functional groups assigned in substrate percentage cover analyses

Phylum	Functional Group
Chlorophyta	Green Corticated Foliose
	Green Corticated Terete
	Green Filamentous
	Green Foliose
	Green Leathery
	Saccate
Rhodophyta	Red Articulated Calcareous
	Red Corticated Terete
	Red Crustose
	Red Filamentous
	Red Foliose
	Red Leathery
Phaeophyceae	Brown Corticated Foliose
	Brown Corticated Terete
	Brown Filamentous
	Brown Foliose
	Brown Leathery
	Kelp
	Kelp Debris

Data Analysis

General Community Structure & Diversity

Species accumulation curves using the Chao-2 and observed number of species (Sobs) estimators, with standard deviation, were produced to assess sampling effort based on faunal species occurrence data collected in both 2009 and 2010 (Cárdenas and Montiel 2015). Data were tested for normality using D'Agostino & Pearson test, which indicated non-Gaussian distribution. Kruskal-Wallis tests were used to examine differences in density between depth and season on the most abundant taxa. These analyses were performed using GraphPad Prism (v8.2.0 2019). Diversity indices were used to assess total species (S), Margalef's richness (d) and Pielou's evenness (J'). The Shannon-Weiner diversity (H') measure was also calculated using log base e, using PRIMER version 7 statistical software (Clarke et al. 2016).

Spatial & Temporal Patterns

A fourth-root transformation was used to down-weigh the influence of highly abundant taxa from the species invertebrate species counts. Two-factor (depth and season) permutated analysis of variance (PERMANOVA) was carried out using the Bray-Curtis dissimilarity measure, on observed species richness data to establish to which extent depth and seasonal changes impact the structure of the community (Anderson et al. 2008). P values were obtained after 9999 permutations. Canonical Analysis of Principal co-ordinates (CAP) was also performed, using a Bray-Curtis resemblance matrix, to further visualise any community differences, with the most abundant taxa overlaid onto the plots as vectors to determine which depth or season were most influential for particular taxa. As the classification groups were *a priori*, CAP was employed to determine the accuracy in which these groups were classified, with similarity profiles (SIMPER) used to detect the contribution each taxon had in driving the differences. Redundancy Analysis (RDA) was carried out to ascertain how substrate type influence species distribution and density, using average depth and percentage cover of bedrock, small boulder, cobble, pebble, gravel, coarse sand, silt, red crustose algae, red foliose algae and dead/drift algae as factors. Non-metric ordination (nMDS) plots for each depth were generated, over which a seasonal trajectory was superimposed in order to establish if the variation of communities displayed a cyclical pattern that aligned with the temporal changes. Porifera sp. 13 proved to be a strong outlier to this result and was therefore removed for the analysis. Multivariate analyses were carried out using PRIMER, except for the RDA which was performed using Brodgar (v2.7.5 2017).

Results

General Community Structure & Diversity

A total of 146 taxa were recorded from 480 photoquadrats, representing an area of 120 m2. Of the 21 classes identified during this survey, the most dominant was Gastropoda which comprised 26 taxa, followed by Ascidiacea with 18 taxa and Demospongiae with 17. The number of taxa per quadrat ranged from 2-29 in 2009 and 5-31 in 2010, with an average of 13 in 2009 and 17 in 2010. The most abundant sessile taxa were Spirorbid worms, with a mean density of 1525.3 individuals m2 (with a range of 0-8080 ± 1572.5 individuals m2). *Pagurus comptus* was the most abundant vagile taxon, with a mean density of 12.7 individuals m^2 (with a range of 0-116 ± 17.6 individuals m^2). The highest number of taxa were found in the Middle depths of both years, with 29 and 37, respectively. Shallow and Middle depths were comprised of *Macrocystis pyrifera* kelp forests, with *Lessonia* sp. and *Macrocystis pyrifera* inhabiting the Deep depths. Substrate cover of the Shallow habitats were dominated by red foliose algae with 45.75% of the total area cover, followed by red crustose algae (25%) and silt (5.95%). Middle depth habitats were dominated by a cover of red encrusting algae (39.6%) followed by red foliose algae (29.4%) and silt, which covered 13% of the substrate. Red crustose algae were also the main substrate cover of Deep habitats, covering 52.8% of the area surveyed, followed by coarse sand (9.6%) and silt (7.6%). The overall algal cover decreased from 82.8% in 2009 to 71.5% cover in 2010, with bedrock and silt cover increasing from 1.4% & 4.5% to 4.5% and 13.0%, respectively.

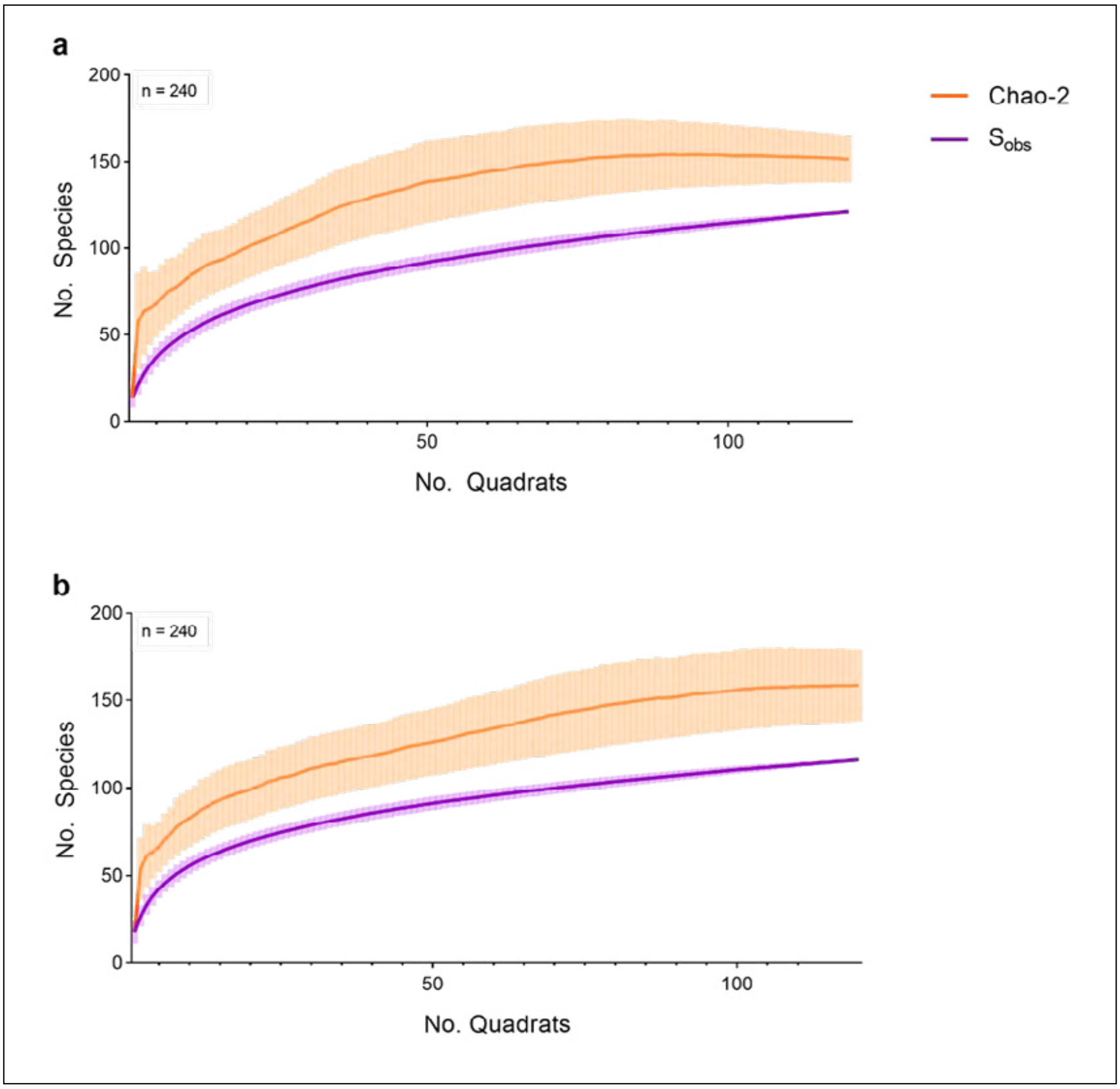

Fig. 1.20: *Species accumulation curves using Chao-2 and Sobs estimators for each year: a 2009 b 2010. Standard deviation shown as surrounding bands.*

The estimated number of species (Chao-2) in 2009 and 2010, 151 and 158, were higher than the observed number of species (Sobs), 121 and 116 respectively, as displayed in Fig. 1.20. The Chao-2 estimations start to reach a plateau suggesting an adequate sampling effort was made, with the majority of species recorded. Total species (S) was highest in the Middle depths across all seasons except spring 2009, as shown in Fig. 1.21, where S was highest in the deeper depths. As seen in Table 1.12, S was generally higher between seasons in 2009 than in 2010, with the exception of summer in both years. Overall, Margalef's richness (d) was higher in 2009 than in 2010. Richness was lowest in autumn 2009 and winter 2010, which were also the lowest seasons of total species. Diversity (H') was highest in all seasons of 2010, with evenness (') being most consistent across the seasons of 2010. H' and J' were both lowest in autumn 2009 and 2010. The highest overall abundances were found in spring, followed by summer in both 2009 and 2010. The highest abundances for each season were found in 2010.

Table 1.12. Diversity indices across seasons of 2009 and 2010.

Year	Season	S	d	J'	H'(loge)
2009	Summer	79	8.230	0.204	0.891
	Autumn	62	6.776	0.175	0.724
	Winter	77	8.484	0.319	1.384
	Spring	74	7.650	0.185	0.796
2010	Summer	84	8.471	0.280	1.239
	Autumn	75	7.507	0.208	0.899
	Winter	67	6.694	0.254	1.069
	Spring	71	6.977	0.235	1.002

Highly significant differences in density (P<0.0001) between Shallow vs. Middle, and Middle vs. Deep communities were observed in *Austrocidaris canaliculata, Ophiocantha vivipara* and *Ophiomyxa vivipara*. Highly significant differences between Middle and Deep depths were identified in communities of *Falsimagarita* sp. and *P. comptus*, with a difference between Shallow vs. Deep waters also highly significant for *P. comptus*. Highly significant differences in depth were also identified in sessile invertebrates, including *Phorbas shackletoni* communities which observed highly significant differences between Shallow vs. Deep and Middle vs. Deep depths. Spirorbid worms displayed highly significant differences in depth between Shallow vs. Middle and Middle vs. Deep strata.

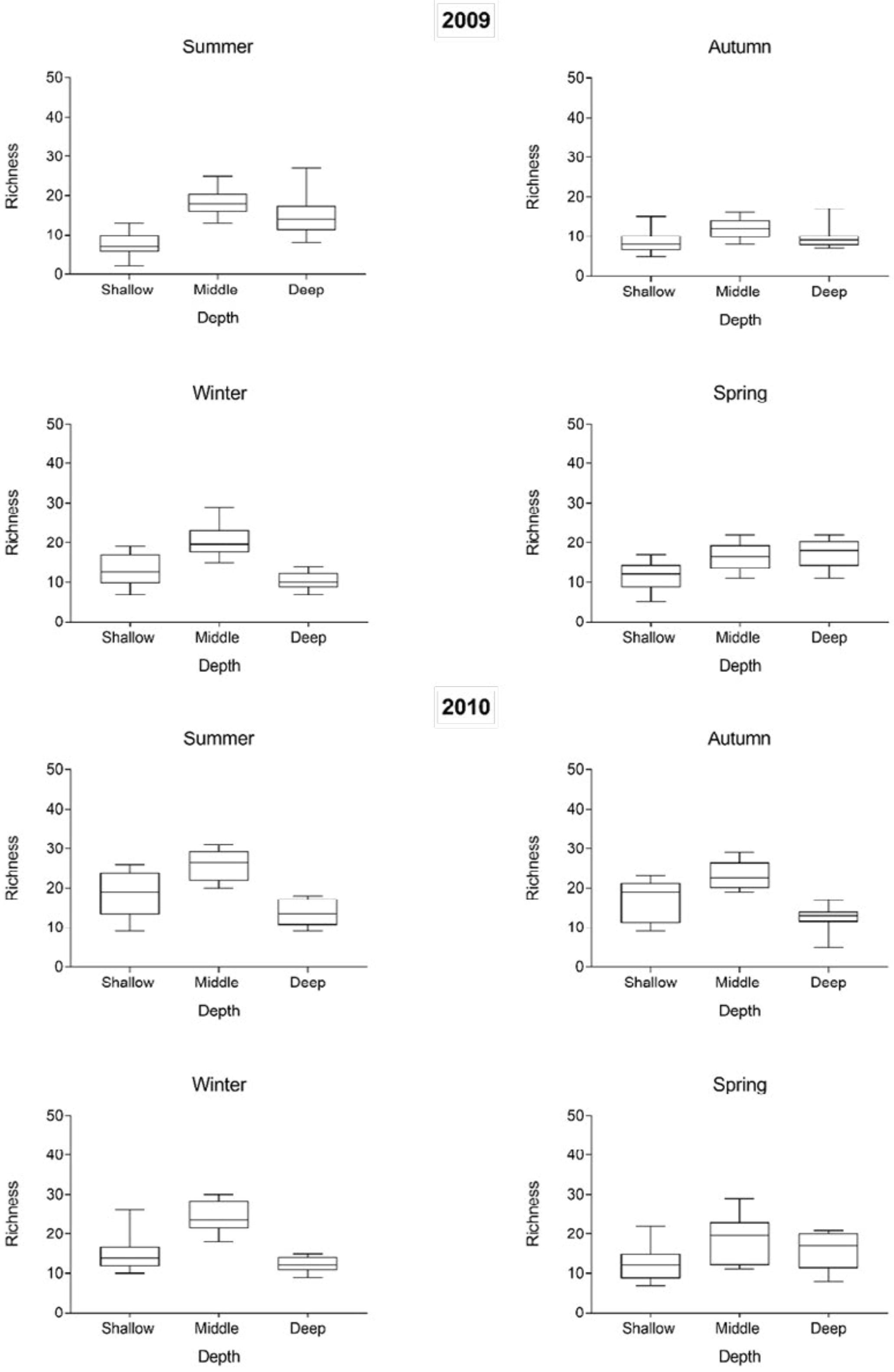

Fig. 1.21: *Richness (Sobs) between depths in each season of 2009 and 2010. Boxes represent 25th, median and 75th percentiles; error bars represent minimum and maximum (n = 20).*

Spatial & Temporal Patterns

A significant difference in species richness (Sobs) was determined between depth and season in 2009 (PERMANOVA depth F= 26.504, P= 0.0001; season F= 10.156, P= 0.0001) and 2010 (PERMANOVA depth F= 37.949, P= 0.0001, season F= 3.5695, P= 0.003) (Table 1.13). Results from PERMANOVA demonstrate that depth and season both influence community structure, with depth having a more significant impact than season. This was confirmed using CAP, as shown in Fig. 1.22, which shows a clear grouping of the Deep quadrats and an overlap in the Shallow and Middle quadrats. CAP showed a high degree of success in classifying quadrat photos into the correct season and depth groups (Table 1.14 & 1.15).

Table 1.13. Results of PERMANOVA two-factor main test, using factors depth and season on shallow benthic communities. P-values obtained after 9999 permutations.

Year	Dissimilarity Measure	Source	d.f.	SS	MS	PseudoF	*P*(perm)
2009	Bray-Curtis	Season	3	6360.7	2120.2	10.156	0.0001
		Depth	2	11066	5533	26.504	0.0001
		Season x Depth	6	6582.5	1097.1	5.2553	0.0001
		Residual	108	22546	208.76		
		Total	119	46555	632.65		
2010	Bray-Curtis	Season	5	3163.2	6725.9	3.5695	<0.05
		Depth	2	13452	463.72	37.949	0.001
		Season x Depth	6	2782.3	177.24	2.6164	0.001
		Residual	106	18787			
		Total	119	38319			

Image: *Flabellina falklandica.* Credit SMSG.

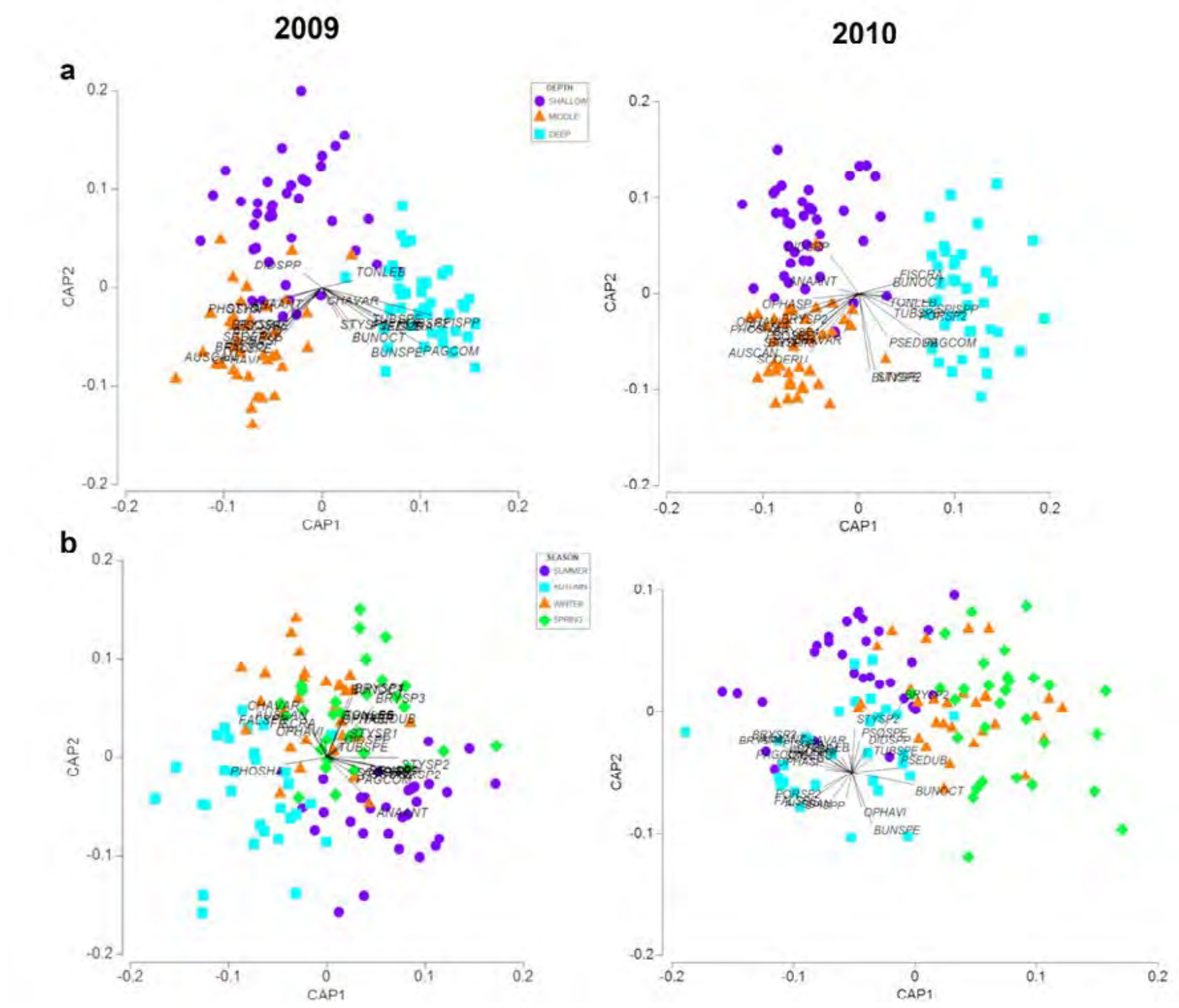

Fig. 1.22: *CAP graphs separating benthic communities in a different seasons and b different depths.*

These classifications ranged from 50% of the groupings correct for 2009 winter quadrats and 2010 summer quadrats to 100% correctly grouped for the 2010 Deep quadrats. The depth groups were more clearly separated on the plots than the seasonal groups, with spring and winter of both years heavily intermixed. Furthermore, an overlay of taxa shows distinct correlations between benthic fauna and depth, though this is not so well defined between seasons. Didemnid ascidians were strongly correlated with Shallow waters, while *A. canaliculata*, *O. vivipara* and *Scopulina erubescens* were among taxa which showed a strong grouping with the Middle depth. *Bunodactis octoradiata*, *P. comptus*, Spirorbid worms and *Tubularia* sp. were found to be strongly correlated with Deep strata.

Table 1.14. Classification of a *priori* seasonal groups in by CAP.

Year	Original Groups	Shallow	Middle	Deep	% Correct
2009	Shallow	30	7	3	75
	Middle	4	36	0	90
	Deep	2	0	38	95
2010	Shallow	34	5	1	85
	Middle	2	37	1	92.5
	Deep	0	0	10	100

The plot depicting invertebrate communities separated by season in 2009 shows a correlation between the sponge *P. shackletoni* and autumn months, and *Anasterias antarctica* correlated with the summer season. The relationships between benthic fauna and season are not clear for 2010, however. SIMPER showed that Bryozoan sp. 1 and Spirorbid worms contributed most to the greatest dissimilarity between Middle and Deep depths in 2009, with Bryozoan sp. 1 and sp. 2 contributing to the dissimilarity between these depths in 2010.

Table 1.15. Classification of a priori depth groups by CAP.

Year	Original Groups	Summer	Autumn	Winter	Spring	% Correct
2009	Summer	21	5	1	3	70
	Autumn	4	19	4	3	63.333
	Winter	4	4	15	7	50
	Spring	5	1	6	18	60
2010	Summer	15	7	8	0	50
	Autumn	10	17	3	0	56.667
	Winter	5	0	17	8	56.667
	Spring	2	0	10	18	60

RDA illustrated that bedrock is a strongly correlated factor of community structure in both years (Fig. 1.23), with a positive correlation not only with the expected sessile fauna, but also with the topsnail Photinastoma taeniatum. This was complemented with the negative correlation between the sessile fauna and coarse sand. Ophiuroids were also shown to be negatively correlated with coarse sand as well as red foliose algae. The positive correlations with average depth were strongest with *P. comptus* in both 2009 and 2010, and Spirorbid annelids were also strongly correlated in 2009 but lesser so in 2010. Average depth was also found to influence Tubularia sp., *Pseudocnus dubiosus* and Porifera sp.2, but to a lesser extent.

Bryozoan sp.1 and Spirorbids contributed to the seasonal variation of community structure across all seasons of this study. Bryozoan sp.2 also contributed to the dissimilarity between Winter and Spring communities, and Spring and Summer communities in 2009. *P. shackletoni* contributed to the change in community structure in Summer and Autumn communities of 2009, and *A. canaliculata* contributed to the variation between communities in Spring and Summer 2009, with 4.19% and 4.07% of the dissimilarity between the community compositions respectively. The seasonal variation between communities is evident in Fig. 1.24, with clear differences in non-dimensional space between communities across both years. A cyclical pattern could be interpreted by the nMDS plots for Shallow and Deep communities, correlated to seasonal change. However, this cycle is not as well defined for the Middle depth communities.

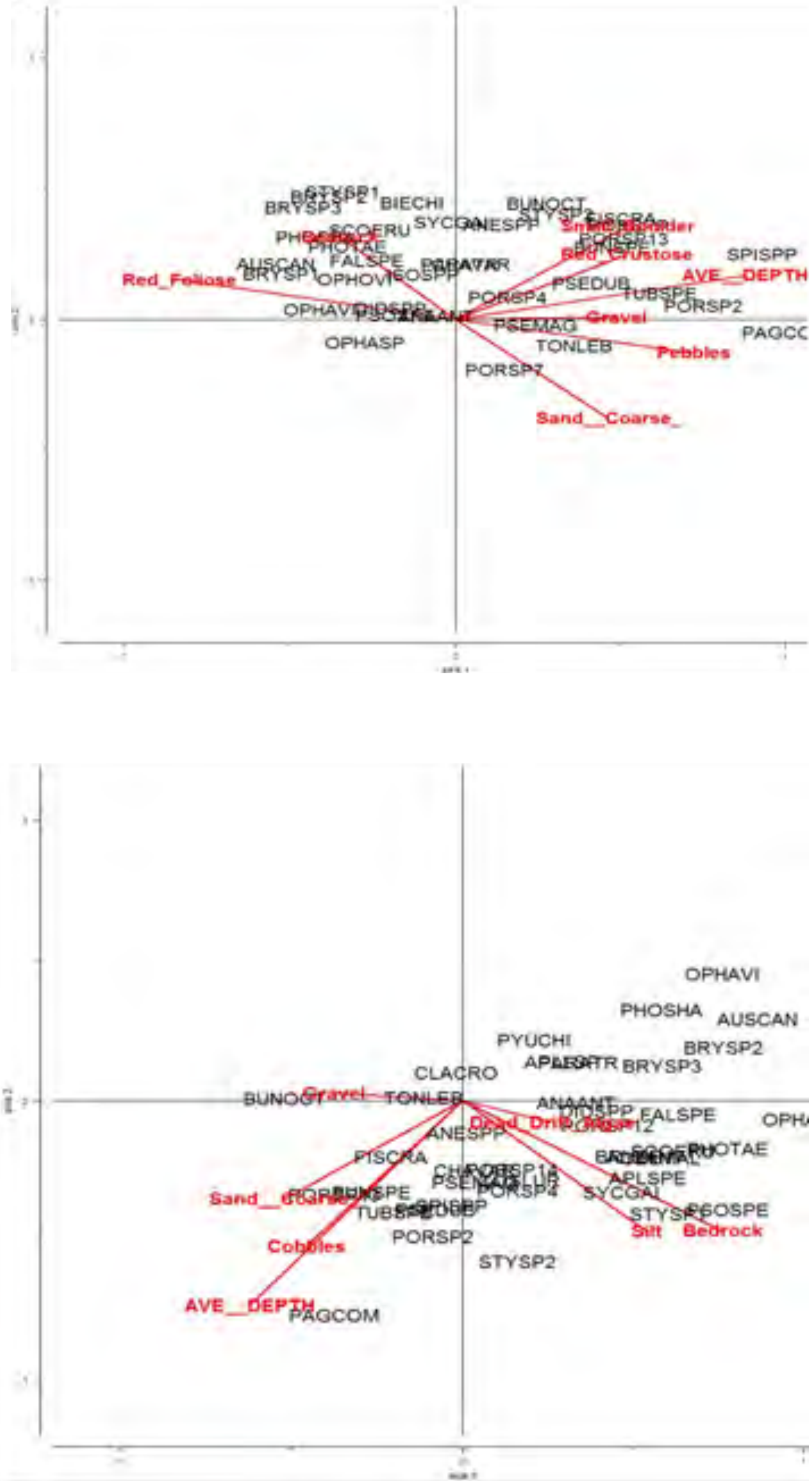

Fig. 1.24: RDA plots with environmental factors influencing community structure for a 2009 and b 2010 depths (ALCANT: Alcyonium antarticum, ANAANT: Anasterias antarctica, ANESPP: Anemone unidentified, APLLSP: Aplysilla sp., APLSPE: Aplidium sp., AUSCAN: Austrocidaris canaliculata, BIECHI: Biemna chilensis, BRYSP1: Bryozoan sp.1, BRYSP2: Bryozoan sp.2, BRYSP3: Bryozoan sp.3, BUNOCT: Bunodactis octoradiata, BUNSPE: Bunodactis sp., CELMAL: Cellaria malvinensis, CHAVAR: Chaetopterus variopedatus, CLACRO: Cladodactyla crocea, COSLUR: Cosmasterias lurida, DIDSPP: Didmenidae unidentified, FALSPE: Falsimargarita sp., FISCRA: Fissurella crassa, ISOSPP: Isopod unidentified, OPHASP: Ophiactis asperula, OPHAVI: Ophiocantha vivipara, OPHOVI: Ophiomyxa vivipara, PAGCOM: Pagurus comptus, PARATR: Pareuthria atrata, PHOSHA: Phorbas shackletoni, PHOTAE: Photinastoma taeniatum, PORSPP: Porifera unidentified, PORSP2: Porifera sp.2, PORSP4: Porifera sp.4, PORSP7: Porifera sp.7, PORSP12: Porifera sp.12, PORSP13: Porifera sp.13, PORSP14: Porifera sp.14, PSEDUB: Pseudocnus dubiosus, PSEMAG: Pseudechinus magellanicus, PSOSPE: Psolus sp., PYUCHI: Pyura chilensis, SCOERU: Scopulina erubescens, SPISPP: Spirorbinae unidentified, STYSP1: Styela sp.1, STYSP2: Styela sp.2, SYCGAI: Sycozoa gaimardi, TONLEB: Tonicia lebruni, TUBSPE: Tubularia sp.).

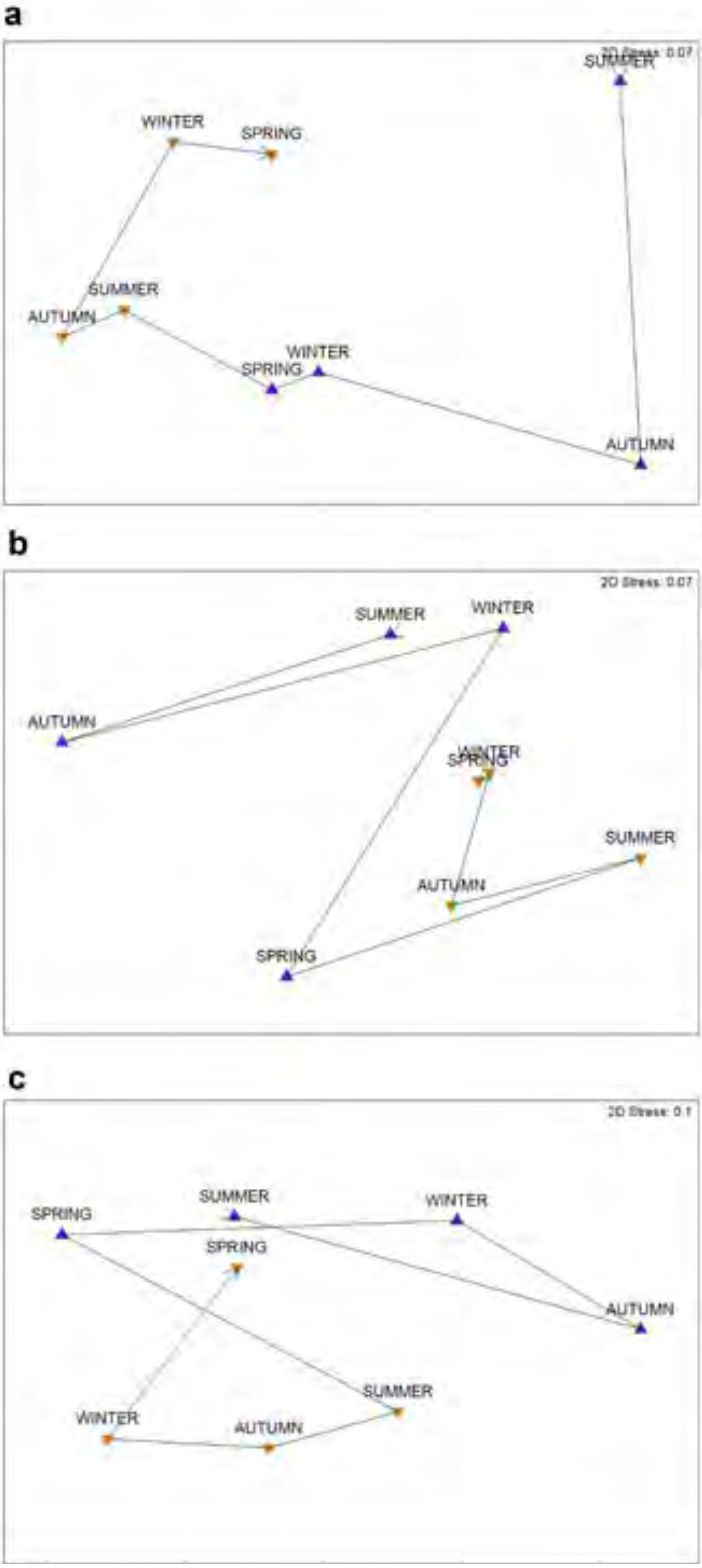

Fig. 1.24: *Non-metric ordination of benthic assemblage abundance separated by a shallow b middle c deep depths with seasonal trajectory superimposed for 2009 and 2010, where ▲ is 2009 and ▼ is 2010.*

DISCUSSION

As far as we know, this is the first study that quantitatively describes the shallow benthic fauna for the Falkland Islands, and examines community level patterns of change in diversity and abundance at small spatial and temporal scales. These results deliver much needed baseline information on the shallow benthic environment on a local scale and the species inventory contributes knowledge to the regional biogeography of southern South America, which has thus far been limited to mainland South America. It is clear that kelp forests are an important marine habitat, providing crucial functions to the community, including nutritional resources, shelter and shade. *Macrocystis* forest communities have a rich faunal diversity, with the kelp forests of the Falkland Islands being no exception.

A total 146 taxa, represented by 121,865 individuals, were recorded in this survey, from 21 classes. The number is within the range recorded in Chilean studies which ranged from 43 to 197 species (Ojeda and Santelices 1984; Ríos et al. 2007; Newcombe and Cárdenas 2011; Sepúlveda et al. 2016; Friedlander et al. 2018). This suggests that the benthic fauna in this region of the Falklands are diverse, particularly in view of the total number of species in this study was also found to be higher than that reported by Aued et al. (2018) who recorded 103 species along the entirety of the Brazilian shallow subtidal region. Diversity (H') was found to be similar to that recorded by Friedlander et al. (2018) in the Magellan Strait.

Shallow transects were dominated by red foliose seaweed, with hard substrate covered with encrusting coralline algae. Taxa found to inhabit this stratum included top-snails *Falsimargarita* sp. and *Photinastoma taeniatum*, whelks *Pareuthria fuscata* and *Pareuthria atrata* and sea urchins *Austrocidaris canaliculata* and *Pseudechinus magellanicus*. These invertebrates are known grazers, for all or part of their diets, and therefore found where algal communities are most abundant (Vasquez et al. 1984). This is supported by the redundancy analyses, showing red foliose algae and drift algae being strong factors for species such as *Falsimargarita* sp., *P. taeniatum* and *A. canaliculata*. Solitary ascidian *Pyura chilensis*, colonial Didemnid ascidians and brittle stars *Ophiactis asperula* and *Ophiocantha vivipara*, were also most abundant in the shallow transects, likely due to high water energy providing an increase in food availability. Didemnid communities were influenced by algae (Red Foliose in 2009 and Drift Algae in 2010) and bedrock, reflecting their habitats of algae thalli and hard bottom substrate. This correlation has also been reported in the Magellan region (Sanamyan and Schories 2003), where it has also been recorded as a dominant taxon in depths of up to 20m. Brittle stars were shown to have a negative correlation with bedrock, along with colonial sessile taxa such as bryozoans. This is not a surprising finding as *O. asperula* were often observed under rocks or in crevices with only the arms extended and *O. vivipara* is known to inhabit hard substrate and algae (pers. obs.; SMSG unpubl. data). In the Middle transects, a reduction in red foliose seaweeds and an increase in encrusting algae and bedrock were recorded. High densities of the Shallow taxa described above were maintained. Bryozoans were found to have the greatest densities in the Middle transects, however depth was not an influencing factor, with bedrock being the most important factor to Bryozoan community structure. In comparison, Cárdenas and Montiel (2015) found no patterns between benthic faunal communities and depth and recorded depth to be a driving factor in bryozoan abundance, however that study focussed solely on sessile taxa. Although abundance increased gradually with depth, Middle depths (10 m-15 m) were found to be more diverse than the Shallow and Deep strata. This is likely to be a result of the Middle strata being a more complex habitat, creating a transition between the Shallow environment, which is highly perturbed due to increased wave energy, to the calmer Deep depths, thus providing a suitable habitat for species found in the Shallow and Deep transects. Deep transects were characterised by a sharp decline in red foliose algae, with coralline algae encrusting bedrock becoming the dominant substrate. This study corroborates the changes in algal communities observed in Chilean investigations, with foliose algae dominating the Shallow strata, and moving towards encrusting algae covering the substrate at Deep depths (Cárdenas and Montiel 2015; Stotz et al. 2016). RDA determined that depth was the strongest correlating factor for the hermit crab *Pagurus comptus* and Spirorbid worms. It may be that, due to their small size, *P. comptus* inhabit more stable environments that are less prone to disturbance than strata at more shallow depths. This may also be the case for *Tubularia* sp., which were also influenced by depth but to a lesser extent, as the stalks are susceptible to damage in high energy environments. As for Spirorbid polychaetes, the recording of depth being the most influential factor can likely be attributed to rock/cobble/pebble scour from storm and gale events in the shallower strata. *Psolus* sp. were still present in this stratum but in significantly smaller numbers, a finding consistent with the view that the species inhabits shallower waters in high latitudes (Giménez and Penchaszadeh 2010). Anemones *Bunodactis octoradiata* and *Bunodactis* sp. were at greatest density in the Deep stratum, contrary to the study by Häussermann (2006), recording the anemone in only Shallow stratum (0 m-3 m).

Temporal variation did not appear to be as significant a factor on the benthic communities as spatial variation. The seasonal trajectories clearly demonstrate variation in community structure following changes in season. The taxon Porifera sp. 13 displayed a strong outlying result in the seasonal trajectories and was therefore removed in order to allow the overall seasonal patterns of the communities to be shown. The trajectories for 2010 display patterns in line with the temporal changes in the Shallow and Deep strata. The Deep stratum is the only 2009 trajectory showing a seasonal cycle. The trajectory of both years in the Deep stratum display a cross-over, however this is a result of the two-dimensional projection and is shown as a cycle in three-dimensional orientation. Density was highest in spring of both years, Ojeda and Santelices (1984) also found a higher overall density in spring in their study in the Beagle Channel. Bryozoan sp.1 and Spirorbid polychaetes were shown to contribute most to the seasonal variation in community structure. Abundance of these taxa were highest in spring and summer of both years, which may reflect the high phytoplankton availability followed by a slow growth period across in autumn and winter (Barnes et al 2007). Linse et al. (2006) have also postulated that the seasonal variations in diversity in the Antarctic and sub-Antarctic may correlate with food availability. Lowest diversity and density were observed in autumn and winter, contrasting the findings from South America (Ojeda and Santelices 1984; Adami and Gordillo 1999; Ríos et al. 2007). However, it should be noted that these studies investigated communities on and in *Macrocystis* holdfasts rather than adjacent substrate. This seasonal abundance may be attributed to recruitment and dispersal of larvae, for example of Decapod crustaceans and Spirorbids (Lovrich 1999; Duggins et al. 1990). *Anasterias antarctica* was recorded in every depth stratum, with maximum density recorded in summer of both years surveyed. This is in contrast to the findings by Laptikhovsky et al. (2015) who observed the highest abundance of the sea star in the Falkland Islands in winter. Furthermore, *A. antarctica* only showed a correlation with Drift Algae in 2010, and no environmental factors in 2009, supporting the findings by Laptikhovsky et al. (2015) that the sea star is found in a variety of strata, from 0m to 20m, from sandy bottoms to rocky reefs. Interestingly, the chiton *Tonicia lebruni* was the only invertebrate observed to migrate between depths during different seasons. The highest densities were recorded for *T. lebruni* in the Deep strata during the winter seasons of both years, but in summer 2010 the highest density was recorded in the Shallow transects. We suggest that this is linked to the brooding season, which occurs in Austral winter (Ituarte and Arellano 2016). As maternal individuals brood their eggs within the pallial grooves (Sirenko 2006), *T. lebruni* may move to deeper depths to a more stable environment to protect their eggs. Brooding in the deeper strata may also allow *T. lebruni* to be protected from predators such as *Anasterias antarctica* (Laptikhovsky et al. 2015), which were shown to have lowest abundance in Deep strata during winter. A significant difference between spring and the other seasons was recorded for *C. crocea*. This is likely a result of brooding, which occurs during autumn and winter, with juveniles released in spring (Martinez et al. 2018).

It is likely that the number of taxa recorded in this study is not representative of all invertebrate fauna inhabiting the shallow benthic region of Kidney Island. As the surveys collected quadrat photos of the benthos, animals under boulders or obscured by algal canopy were not recorded. This limitation of quadrat photography, such as an increase in pixilation as zoom is increased, has previously been highlighted by studies such as those by Foster et al. (1991), Preskitt et al. (2004) and Bowden (2005). Furthermore, despite the high resolution at which the quadrat photos were taken, identification to highest taxonomic level was not possible for some taxa such as sponges and bryozoans, where microscopy is usually required for species-level identification (Pech et al. 2004; Van Rein et al. 2011; Goodwin et al. 2011, 2016).

Further studies around the Falkland Islands are required to determine if the spatial and temporal patterns in this study are consistent throughout the shallow benthic region of the archipelago. It is already known that significant changes in fish species abundance has occurred around the Falkland Islands (Arkhipkin et al. 2013), and changes in community composition have been observed to vary between sites in South Georgia and southern South American investigations (Barnes et al. 2006; Ríos et al. 2007; Montiel et al. 2011). Interesting patterns in benthic faunal species distribution have been observed, with high species richness is found in the north-west and decreasing towards the south-east of the Islands. The diversity of algae in the Falkland Islands may follow a similar pattern. Large scale investigation on the distribution of benthic invertebrates around the Falklands will address the gaps in knowledge of shallow benthic faunal distribution in the Islands. It is also recommended that surveys are continued at Kidney Island, to determine if patterns exist at larger temporal scales.

As the first description of invertebrate faunal communities inhabiting *Macrocystis pyrifera* forests of the Falkland Islands, this study demonstrates how the diverse marine faunal communities of this shallow benthic region are impacted by small spatial and temporal variation. The results of this study provide important knowledge on the ecological patterns of the Falklands and contribute knowledge to the wider region of southern South America which, until now, has been limited to the Magellan Region.

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CHAPTER 2

OFFSHORE MARINE MANAGED AREAS

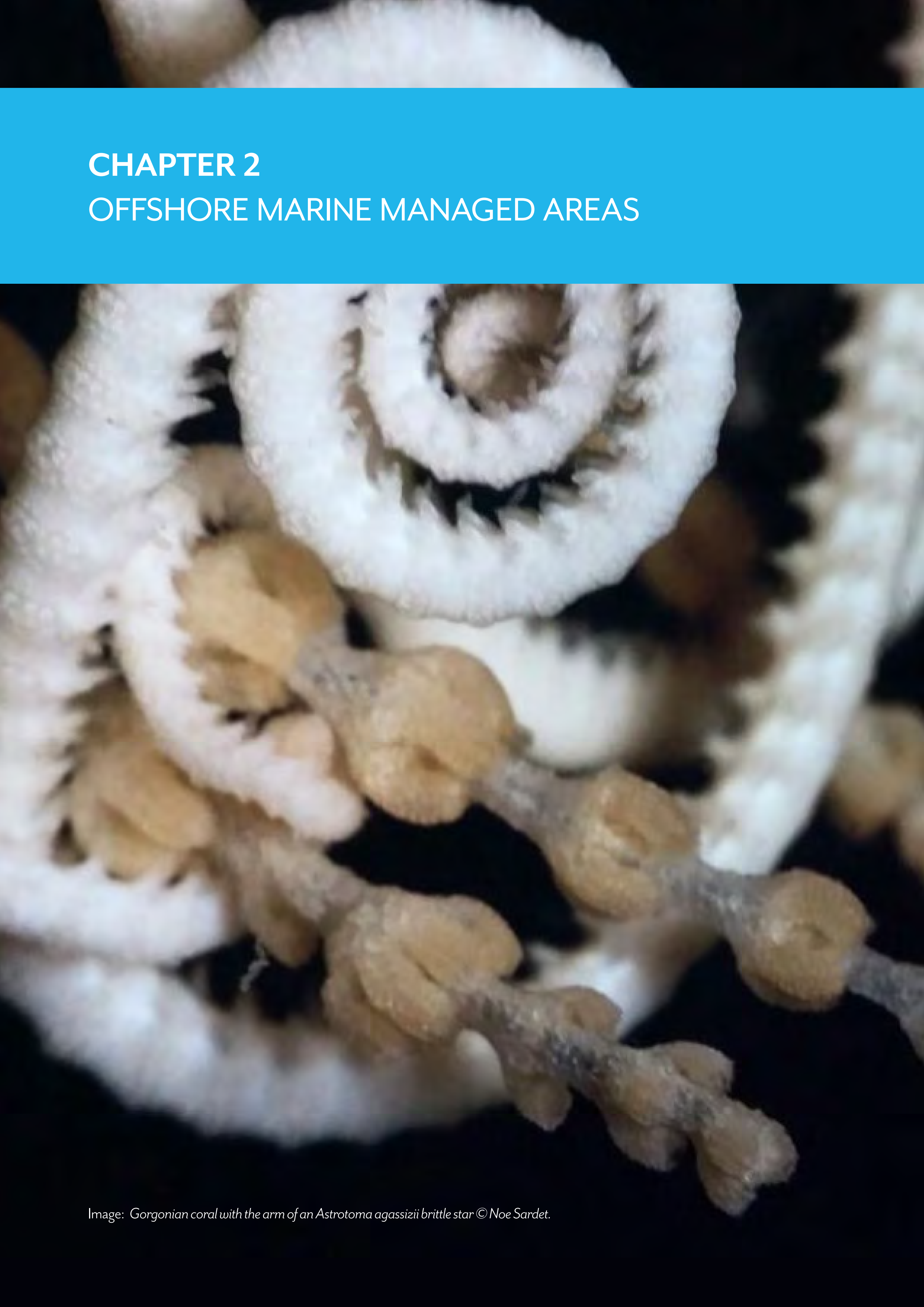
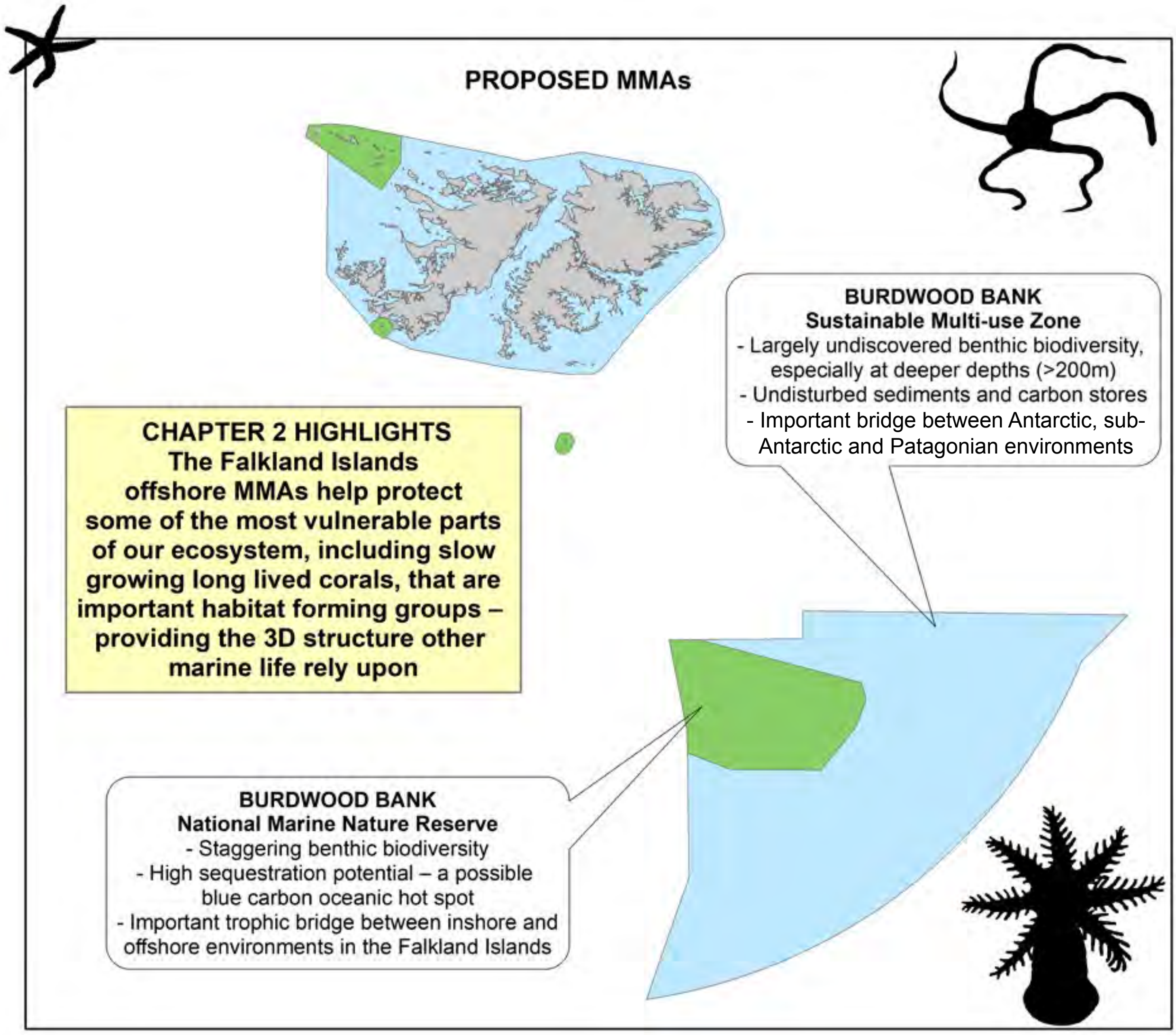


Image: *Gorgonian coral with the arm of an Astrotoma agassizii brittle star © Noe Sardet.*

CHAPTER 2 CONTENTS

CHAPTER SUMMARY

Chapter 2 focuses on the offshore ecosystems proposed for designation as Marine Managed Areas (MMAs) - considered the great unknown region of our planet, biodiversity estimates are lacking for deeper environments globally, as most deep-sea ecosystems are only recently discovered. The deep Falklands is no exception, however, exploration has increased in recent years, and interesting patterns of discovery are emerging as a result. Deep seafloor environments are defined as Vulnerable Marine Ecosystems (VMEs) - considered isolated areas of high biodiversity and productivity. The VME indicator taxa such as corals, sponges, bryozoans, sea stars and brittle stars scatter seafloor environments with life, contributing key ecosystem services such as habitat for other animals and carbon storage and sequestration blue carbon. This chapter covers; VMEs and sustainable fisheries, blue carbon and biogeographic patterns, providing insights into the conservation significance of the Falkland Islands offshore MMAs on the Burdwood Bank.

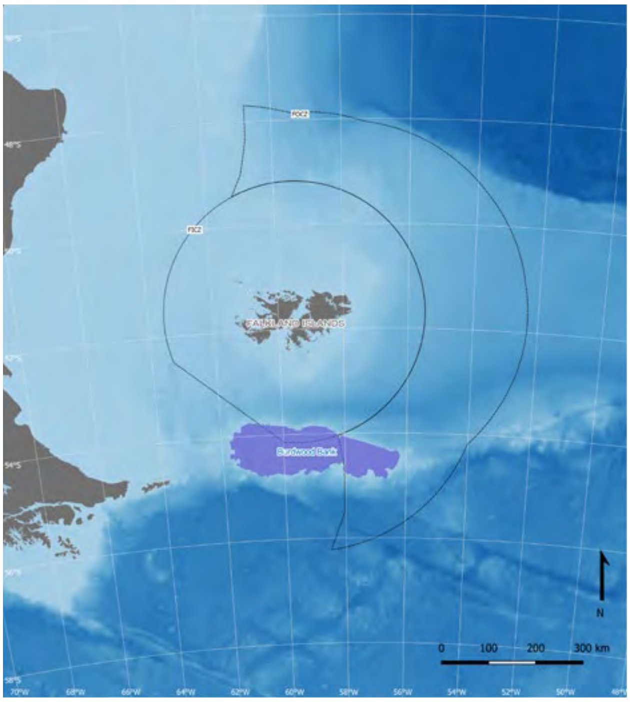


PROPOSED MMAs

BURDWOOD BANK
Sustainable Multi-use Zone
- Largely undiscovered benthic biodiversity, especially at deeper depths (>200m)
- Undisturbed sediments and carbon stores
- Important bridge between Antarctic, sub-Antarctic and Patagonian environments

CHAPTER 2 HIGHLIGHTS
The Falkland Islands offshore MMAs help protect some of the most vulnerable parts of our ecosystem, including slow growing long lived corals, that are important habitat forming groups – providing the 3D structure other marine life rely upon

BURDWOOD BANK
National Marine Nature Reserve
- Staggering benthic biodiversity
- High sequestration potential – a possible blue carbon oceanic hot spot
- Important trophic bridge between inshore and offshore environments in the Falkland Islands



Map illustrating the Falkland Islands Conservation Zones (FCZs), and the geographic position of the Burdwood Bank in relation to the Patagonian Shelf Large Marine Ecosystem (LME), considered part of the Magellanic Biogeographic Province.

THE KEY FINDINGS OF THIS CHAPTER INCLUDE:

2.1 Offshore: Vulnerable Marine Ecosystems and fisheries

- The National Marine Nature Reserve (NMNR) and Sustainable Multi-use Zone (SMZ) encompass the eastern Burdwood Bank. We review the unique and fragile seafloor taxa, known as VME indicator taxa, and their habitats.
- Coral communities are hypothesised to be particularly vulnerable to the effects of bottom contact fisheries, exemplifying their designation as VME indicator taxa.
- The creation of the NMNR and the SMZ Burdwood Bank MMA will help to ensure the long-term resilience of shelf and slope habitats and dependent species, as well as the sustainability of economically important fisheries by protecting connectivity between neighbouring biodiversity refugia.

2.2 Offshore: Offshore: Blue carbon and Vulnerable Marine Ecosystems on the Burdwood Bank

- Seafloor blue carbon is broadly defined as the CO_2 absorbed from the atmosphere by marine ecosystems, which is ultimately sequestered for 100s to 1000s of years. There is an emerging basis for this research in the Falkland Islands.
- Preliminary research suggests that the Burdwood Bank hosts high carbon storage and sequestration potential.
- Newly identified carbon rich biodiversity habitats including abundant Stylasteridae (lace) and scleractinian (cup) coral assemblages add to the conservation significance of the Burdwood Bank MMA.
- A focus on maintaining ecosystem function at the site of sequestration, where it is most crucial to long-term climate mitigation, includes conservation of VME taxa (such as corals)

2.3 Offshore: Fish and squid communities of Burdwood Bank and the southern Patagonian Shelf – further insights into biogeography of the region

- The Burdwood Bank has high biological diversity compared to other parts of the Falkland Islands and High Seas area to the north of the FCZs with regards to fish and squid. Possibly because of its proximity to the Antarctic Circumpolar Current (ACC).
- The Burdwood Bank represents a meeting of sub-Antarctic and Magellanic fauna.
- Recognition of the Burdwood Bank as unique is building across the literature for multiple VME taxa, the inclusion of fish and squid community dynamics into the mix, along with data on the migration of marine higher predators means that the Burdwood Bank could theoretically be described as a province in and of its own right - a globally important ecosystem.

WHAT IS UNIQUE ABOUT THE OCEANOGRAPHY OF FALKLAND ISLANDS?

The Patagonian Shelf and Slope, together with the Falkland Islands, comprise the Patagonian Shelf Large Marine Ecosystem (LME) - one of the most productive areas in the southwest Atlantic. This productivity stems, in part, from the unique oceanography of the region. Marine currents upwell from cold sources such as the sub-Antarctic, the Falkland Current and divergence between the Antarctic Circumpolar Current in the Drake Passage. At the continental slope and Burdwood Bank, the Falkland Current splits into a weaker branch flowing west and a stronger branch flowing east around the Islands (Bianchi et al. 1982). The eastern branch forms the long Falkland Current Front that runs along the Patagonian Shelf break and slope from north of Burdwood Bank to the latitudes of La Plata Estuary (Acha et al. 2004; Franco et al. 2008), consisting of several meso-scale fronts of intensified productivity (Arkhipkin, et al. 2013). Warmer waters are also transported from sub-tropical origins, transported onto the shelf by the Brazil Current. These currents of tropical, temperate and polar origins mix with temperate Falklands shelf waters to create unique biogeographic linkages - reflected in the diversity of marine life found in Falklands waters.

WHAT IS THE PATAGONIAN SHELF LARGE MARINE ECOSYSTEM (LME)?

The LME encompasses the latitude 46° 16’ 15.3” S and longitude 61° 37’ 5” W and is an important geographic region, which includes the Magellanic biogeographic province. The Falkland Islands offshore environments are considered part of this larger ecosystem and province. However, the habitats and species found on the seafloor and the commercially and non-commercially important fish and squid communities found in the Falklands also represent unique characteristics and community dynamics found nowhere else on the planet.

WHAT IS UNIQUE ABOUT THE OCEANOGRAPHY AND GEOGRAPHIC POSITIONING OF THE BURDWOOD BANK?

In offshore southern Falklands waters, the Burwood Bank, is considered analogous to a ‘production engine’ for the Patagonian Shelf LME. The entire Burdwood Bank is 300 km long and 60 km wide. Its 200 m deep summit features smaller bulges, some of which reach to within 50 m of the surface in parts. The Burdwood Bank forms the beginning of the Scotia Arc, which is a geographic barrier to the northward flow of the Antarctic Circumpolar Current (ACC), and an important island chain linking and isolating biodiversity and migration routes over-time. This productive ecosystem is an important migration destination for a wide variety of seabirds, marine mammals and demersal and pelagic fish, with a stunning variety of invertebrate fauna on the seafloor. This means the Burdwood Bank is uniquely positioned as an oceanographic ‘meeting point’ with multiple origin points from the Antarctic in the south and more temperate environments in the north.

A brittle star, possibly a juvenile *Astrotoma agassizi*, clinging to a Stylasteridae (lace) coral skeleton.

2.1 OFFSHORE: VULNERABLE MARINE ECOSYSTEMS AND FISHERIES

In 2020 SAERI published a paper on spatial patterns of Vulnerable Marine Ecosystem (VME) indicator tax in the Falkland Islands. This section provides an overview of this research and a summary of the spatial information presented in the publication: *Brewin, P.E., Farrugia, T.J., Jenkins, C., and Brickle, P. (2020). Straddling the line: high potential impact on vulnerable marine ecosystems by bottom-set longline fishing in unregulated areas beyond national jurisdiction. ICES J. Mar. Sci. 78(6), 2132-2145. doi:10.1093/icesjms/fsaa106.*

Summary of: Straddling the line: high potential impact on vulnerable marine ecosystems by bottom-set longline fishing in unregulated areas beyond national jurisdiction.

KEY TAKE-AWAY POINTS:

- VME indicator taxa are not well described in the South West Atlantic, and as a consequence species occurrences are aggregated into higher taxonomic groupings, which gives less resolution to spatial patterns to inform MMA designations.
- There is currently one fishery that operates within the boundaries of the SMZ, it is Marine Stewardship Council (MSC) certified and it is composed of a single long-line fishing vessel that operates within Falklands waters all along the edge of the continental shelf. Brewin et al. (2020) demonstrated that the impact from this fishery between 600 – 1800 m on VMEs was minimal compared to unregulated fisheries outside the FCZ.
- This study also included areas within the proposed Burdwood Bank SMZ and provides recent information of VMEs within this area.

Spatial patterns of VMEs in the Falklands Conservation Zones (FCZs):

- Cnidarian groups were most common in the FCZ, particularly the Scleractinia (23.06%), Gorgonacea (15.41%), Alcyonacea (7.90%), and Stylasteridae (7.39%).
- MaxEnt model predicted taxa distributions show that some VME taxa are widely distributed across the FCZ and Areas Beyond National Jurisdiction (ABNJ), such as Scleractinian corals and sponges.
- The cnidarian group Pennatulacea (sea pens) is a model taxa used to indicate habitats that might not be represented by other VME groups.
- Benthic camera imagery collected in the FCZ toothfish fishing grounds indicated a patchiness of VME indicator taxa group distribution (especially encrusting taxa).
- Longline-mounted cameras captured evidence of disturbance by "trotline" longline gear to the seabed. These were indicated by the presence of narrow furrows (20 cm in width) in soft sediments, caused during hauling. Dropline weights may also strike patches of VME indicator taxa attached to hard substrates in areas of soft sediments.

Spatial patterns relating to the Burdwood Bank SMZ:

- The predicted distribution of Pennatulacea (sea pens) is narrowly restricted to the North-western flank of the Burdwood Bank.
- The octocoral (soft) coral group, Alcyonacea predicted habitat is mostly around the northern edge of the FCZ surrounding the Burdwood Bank.
- Stylasteridae (lace) coral habitat was also well represented along the Burdwood Bank (FCZ) and North Scotia Ridge (ABNJ) but had less probability of occurrence to the north within the FCZ or in adjacent ABNJ.

Fisheries footprint in the FCZ, including the SMZ versus ABNJ:

- Predictive modelling was used to compare the footprint of fishing in licensed areas, such as the Burdwood Bank, versus unlicensed Areas Beyond National Jurisdiction (ABNJ). Results suggest that the ABNJ fishery footprint could be almost twice as large as in licensed waters.
- The total area of fishing footprint determined by Brewin et al. (2020) for both the FCZ and ABNJ is 36 924km^2, and the total footprint of actual fished ground in the ABNJ is almost twice as large as the FCZ (23 928 and 12 997 km^2).
- The predicted habitat for each VME indicator taxa group within the FCZ is an order of magnitude larger than the predicted habitat in the ABNJ.
- Predicted VME habitats are larger in the FCZ, compared to ABNJ but the fishing footprint is similar, this means that the percentage fishing footprint of predicted area of VME indicator taxa was an order of magnitude lower than ABNJ.
- The total fishing footprint area within predicted habitats was relatively similar for FCZ and ABNJ fisheries for all coral groups.

FUTURE WORK:

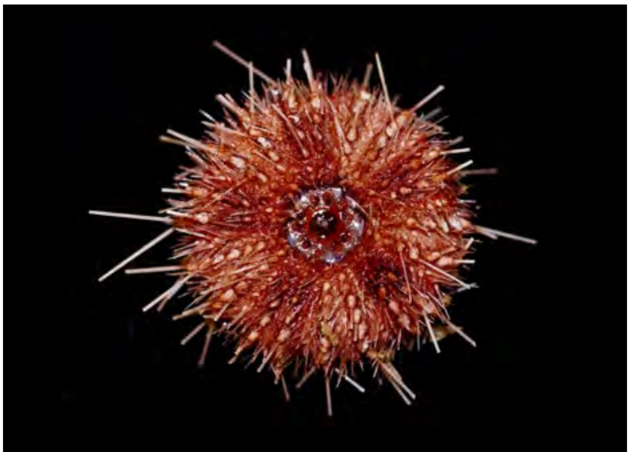
- A more detailed examination of the relative impact of different longline gear types is needed to better understand the impacts of longline fishing on VMEs particularly in areas where mixed gear types are used as it is most likely that multiple gear types are used in the ABNJ adjacent to the FCZ.
- A discontinuity of management for VMEs could have detrimental consequences for the resilience and/or recovery of locally isolated VME taxa populations, and more information on recruitment, dispersal, and sources and sinks of connectivity are needed.
- Ocean currents flow suggests that the Falkland Islands VME populations may act as a source to ABNJ. However, without biological data, this hypothesis cannot be tested.
- The results of Brewin et al. (2020) suggested further investigation into sea pen biology and ecology in the Falklands. An action that is currently in progress through the work of Dr Tabitha Pearman at SAERI.
- Brewin et al. (2020) suggest that improved species identifications, in particular for corals such as Gorgonace or Stylasteridae will improve habitat predictions where patchiness of hard substrates was identified. This work is currently underway through the research of Dr Narissa Bax at SAERI for coral groups such as scleractinia and Stylasteridae, in combination with collaborative taxonomic networks for other VME indicator taxa such as sponges for Burdwood Bank specimens.

SUMMARY:

Brewin et al. (2020) assessed the impact of the Patagonian toothfish (*Dissostichus eleginoides*) fishery on Vulnerable Marine Ecosystems (VMEs), a bottom-set longline fishery in the Falkland Islands. This study used predictive modelling to compare the footprint of fishing in licensed areas, such as the Burdwood Bank, versus unlicensed Areas Beyond National Jurisdiction (ABNJ). Results suggest that the ABNJ fishery footprint could be almost twice as large as in licensed waters. This result highlights that, despite the main area of VME indicator taxa being found within Falklands jurisdictional waters, there are important VME habitats on the adjacent high-seas that are potentially highly impacted by unregulated fishing. Maintaining protections and sustainable practices in Falklands jurisdictional waters will be an important aspect of governance and monitoring procedures - of particular importance to the proposed Burdwood Bank Marine Managed Area (MMA) National Marine Nature Reserve (NMNR) and Sustainable Multi-use Zone (SMZ).

INTRODUCTION:

Fisheries pressures and demands are increasing globally and locally (Halpern et al. 2015), consequently, so are the associated impacts of fishing on species and habitats that directly or indirectly support fisheries productivity (Borja et al. 2016). Seabed (bottom-contact) fishing methods can be particularly destructive to deep-sea benthic ecosystems (Clark et al. 2016 for review), causing long-lasting damage (Hiddink et al. 2017, Amoroso et al. 2018, Roberts, 2002; Wright et al. 2019), particularly to Vulnerable Marine Ecosystems (VMEs) (FAO, 2008). The term VMEs encompasses multiple species and habitats which house comparatively high amounts of biodiversity and productivity, contributing to multiple important ecosystem services (Rogers et al. 2007). Key VME indicator taxa are known as ecosystem engineers, because they form the foundational structure of seafloor habitats, performing roles such as nutrient cycling and providing refuge to associated marine life.



Sea urchin, *Sterechinus agassizii*, from the Burdwood Bank

Common VME taxa include, stony corals such as Scleractinia (cup) corals, Stylasteridae (lace) and Octocorals (soft) corals, sea fans, sea pens, anemones, and sponges (e.g. Roberts et al. 2006; Rogers et al. 2007). These taxa support a wide range of invertebrate and fish populations (Henry and Roberts, 2007), and are particularly vulnerable to impacts of fishing gear because of their life history characteristics (e.g. long-lived, slow growing, late to reproduce) and their distribution across regionally isolated features such as seamounts and ridges, where fisheries are often targeted (sensu Leibold et al. 2004; Thrush et al. 2013). It is therefore imperative that policy makers and fisheries implement sustainable practices, which consider the resilience and recoverability of benthic ecosystems (EC, 2008; Borja et al. 2016).

Best practice in line with global standards determined under the United Nations General Assembly (UNGA) Resolution 61/105:80, recommends precautionary protection and management of VMEs among deep-sea fisheries with the aim of conserving regional biodiversity as well as protecting the ecosystem that supports fish stocks (UNGA, 2007; FAO, 2008).
Brewin et al. (2020) consider that on the high seas the Regional Fisheries Management Organisations or Arrangements (RFMO/A) are ''encouraged to identify, monitor, and regulate impacts of fishing on VMEs''. Uptake is known to vary between RMFO/As (e.g. Watling and Auster, 2017). In theory, RFMO/A recommendations can occur in harmony with the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), Resolution 10/XII that states, in areas adjacent to the Convention Area, Member States should operate "responsibly and with due respect for the conservation measures it had adopted under the Convention". However, Brewin et al. (2020) note that ''this applies only to areas where there is an RFMO/A in the adjacent waters to which fishing operations can be harmonised. Of concern are the large areas of the high-seas that are not managed by any RFMO/A with respect to bottom fishing (FAO, 2016); management of those areas is left to the discretion of the Flag State''. Furthermore, the accurate assessment of fisheries impacts on VMEs is logistically challenging, especially in deep waters, and areas beyond national jurisdictions (ABNJ) (Clark et al. 2006). Brewin et al. (2020) fill this knowledge gap to understand the impact of the Patagonian toothfish (*Dissostichus eleginoides*) fishery on VMEs operating in the Falkland Islands and the adjacent high-seas (Fig. 2.1).

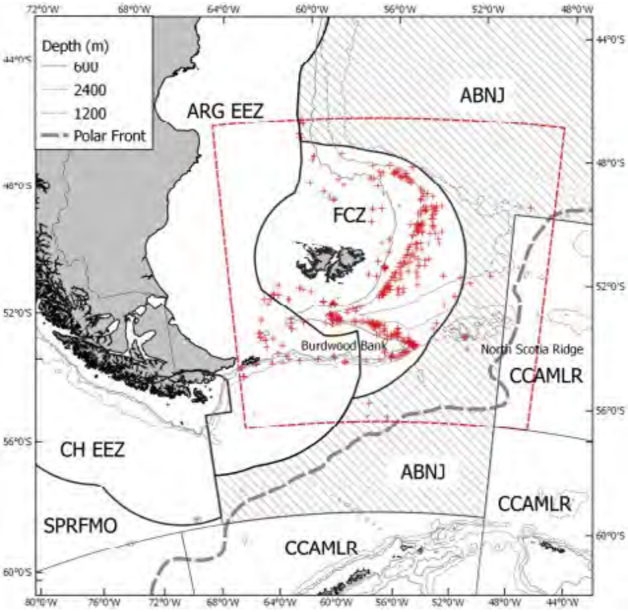


Fig. 2.1 *Managed fishing areas of the Patagonian Shelf indicating the Falkland Islands Conservation Zones (FCZ), Argentina EEZ (ARG EEZ), Chile EEZ (CH EEZ), South Pacific Regional Fisheries Management Organisation (SPRFMO), and the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). ABNJ (shaded) are areas not managed. Depth and the Antarctic Polar Front are indicated. Also shown are the MaxEnt model domain (red dashed line) and taxa sample occurrences (red crosses) input into the model. Source: Brewin et al. (2020).*

THE FALKLAND ISLANDS TOOTHFISH (*DISSOSTICHUS ELEGINOIDES*) FISHERY

The Falkland Islands' toothfish fishery is a licensed and a Marine Stewardship Council (MSC) certified fishery (**www.msc.org**). The fishery operates year-round in the Falkland Islands Interim Conservation Zone and Falkland Islands Outer Conservation Zone (herein collectively referred to as the FCZ) between 600 and 1800 m depth (Fig. 2.1). Fisheries operations are conducted using bottom-set baited hook and line systems anchored to the seabed to target the common seabed habitat of toothfish (Collins et al. 2010). In the FCZ this operation is composed of a "trotline", a longline system consisting of clusters of hooks hanging from a single mainline suspended above the seabed. This system also includes the use of cetacean exclusion nets, known as "umbrellas" or "cachalotera" (Brown et al. 2010). Brewin et al. (2020) note that ''Immediately adjacent to the FCZ on the high-seas around the north, north-east, and east of the FCZ along the North Scotia Ridge, unlicensed longline vessels also target Patagonian toothfish''. There are no publicly accessible data available from the RFMO/A on gear type, total catch, fishing effort, inhibiting region-wide analyses to assess fishing impacts relating to the Falkland Islands (and near-by controlled fisheries of Chile and Argentina, RFMO/As, the South Pacific Regional Fisheries Management Organization (SPRFMO) and CCAMLR (Fig. 2.1).

VME indicator taxa are commonly encountered as by-caught in deep-sea demersal longline fisheries (e.g. Muñoz-Ramírez et al. 2011). Demersal longline fishing methods may have lower impacts on VMEs compared to other bottom impact fishing (e.g., bottom trawling), because the weighted line remains mostly stationary on the seabed, with a long and narrow physical footprint area (Pham et al., 2014; Welsford et al. 2014). However, Brewin et al. (2020) outline that conservation concerns remain, and by-catch assessments of VME indicator taxa vary between species groups, based in part upon, ''an effect of catchability rather than actual impact (Parker and Bowden, 2010; Muñoz-Ramírez et al. 2011; Welsford et al. 2014)''. Additionally, the natural range, abundance and distribution varies, and/or is unknown for many VMEs, making it difficult to understand the cumulative impacts of longline fishing (Sharp et al. 2009; Pham et al. 2014; Welsford et al. 2014).

Brewin et al. (2020) examined the regional footprint and fishing effort of deep-sea bottom-set longline fishing on VMEs in the region of the Patagonian Shelf, South West Atlantic. They aimed to:

(i) describe VME indicator taxa distribution throughout the region of Patagonian toothfish longline fishing using a presence-only species predictive distribution model and
(ii) assess the comparative potential impact of fishing effort on VME indicator taxa within a domestic licensed fishery and an unmanaged fishery in the adjacent ABNJ.

The Brewin et al. (2020) study compared predicted VME taxa distribution maps to vessel e-log book recorded effort within jurisdictional waters and, in the adjacent ABNJ, S-AIS (Satellite—Automatic Identification System) data gathered by Global Fishing Watch (GFW) (Kroodsma et al. 2018).

Brewin et al. (2020) discuss the implications of fishing exposures across contiguous VME habitats with recommendations for improved VME conservation in the region. This summary focuses on these aspects that pertain to the proposed Burdwood Bank MMAs.

MATERIAL AND METHODS

Ecological setting

The Falkland Islands in uniquely positioned in a highly productive region of the Patagonian Shelf Large Marine Ecosystem (Marrari et al. 2017), and the southern flank of the shelf connects to Tierra del Fuego in the west and the Burdwood Bank south of the Falkland Islands, and the North Scotia Ridge (Fig. 1), part of the Scotia arc, continuing eastward eventually reaching the Sub- Antarctic Island of South Georgia. The eastward flowing Antarctic Circumpolar Current (ACC) water branches northward at the Burdwood Bank forming the Falklands Current, whilst the main ACC flows east along the North Scotia Ridge (Arhan et al. 2002). There are few descriptions of VME species assemblages in the region. The notable exception is work conducted west of the Burdwood Bank in the Argentinean EEZ where the Namuncurá Marine Protected Area was established in 2004 (Schejter et al. 2016), albeit considerably shallower (200m depth) than the region examined in the Brewin et al. (2020) study from 600 - 1800 m.

Modelling approach

Brewin et al. (2020) used the species presence-only distribution model MaxEnt (Phillips et al. 2006), a machine-learning style species distribution model (SDM) (Merow et al. 2013), to predict habitat suitability for VME indicator taxa (**CCAMLR VME Taxa Classification Guide 2009**), similar to other geographic studies on VME indicator taxa distribution in deep-sea habitats (e.g., Tittensor et al. 2009; Ross and Howell, 2012; Anderson et al. 2016b). The Brewin et al. (2020) model domain (47–57 S, 50–65 W) encompasses toothfish bottom-set longline fishing on the Patagonian Shelf/slope and inclusive of ABNJ fished areas to the northern continental shelf edge, south to deep water beyond the Burdwood Bank, and east along the North Scotia Ridge (Fig. 1). Depths shallower than 300m, and deeper than 2000m were excluded to eliminate potentially confounding environmental variables at near-shore and/or near-abyssal depths and biases were also considered where possible to do so (see references from Brewin et al. 2020 methods section: Anderson et al. 2016b, Phillips and Dudı´k, 2008, Kramer-Schadt et al. 2013, Guillaumot et al.,2018, Ross and Howell, 2012, Halvorsen, 2013).

TAXA DATA

Brewin et al. (2020) incorporated taxa presence data from local and online sources, including:

(i) The Falkland Islands Government Fisheries Department Scientific Observer database of benthic invertebrate species occurrences, identified to the lowest practical taxonomic level from January 2012 (when records began) to December 2016.

(ii) **The Ocean Biogeographic Information System (OBIS)**

(iii) A total of 2945 georeferenced benthic still images from hydrocarbon exploration throughout the FCZ (Falkland Islands Government Department of Mineral Resources, unpublished data)

(iv) A total of 29 video recordings during two research cruises conducted in 2017 and 2018 on the commercial toothfish longline vessel CFL Hunter (Farrugia and Keningale, 2018; Farrugia et al. 2018), to gain an insight into longline dynamics and impacts on the seabed (e.g. Welsford et al. 2014).

VME indicator taxa are not well described in the South West Atlantic, and as a consequence species occurrences were aggregated into higher taxonomic groupings according to the **CCAMLR VME Taxa Classification Guide 2009** (Parker and Bowden, 2010).

PREDICTOR DATA

Brewin et al. (2020) considered the mean and variability (Huston, 1999; Leichter and Witman, 2009) of 38 environmental predictor variables of VME indicator taxa distributions, and after screening settled on 25 variables listed in Table 1 for their final base model (Anderson et al. 2016b), and they noted aragonite saturation state and depth as highly correlated. Consequently, aragonite saturation state was retained in models for hard corals (Stylasteridae and Scleractinia) due to its importance in their structure.

Brewin et al. (2020) determined the percentage overlap of fishing footprint on predicted habitats, and reduced probability maps to maps of binary distributions (e.g., Ross and Howell, 2012) and "average predicted probability/suitability approach" (Liu et al. 2005), and separate thresholds for each taxa group. Their threshold method allowed for a wider predicted spatial distribution, to account for taxonomic groups rather than individual species distributions, and a conservative prediction of a broad environmental niche for grouped taxa compared to the narrow niche of individual species.

Table 2.1: Predictor variables tested in MaxEnt model. Source: Brewin et al. (2020).

Environmental variable	Units	Native resolution (o)	Temporal resolution	Source	Reference
Seabed terrain					
Bathymetry[a]	M	0.0083	–	https://www.gebco.net	GEBCO_2014 (v20150318)
Slope[a]	Degrees	0.0083	–	Derived from Bathymetry	Hogg et al. (2016)
Bathymetric Position Index (BPI) - broad[a]	-	0.0083	–	Derived from Bathymetry	Anderson et al. (2016a)
BPI - fine[a]	-	0.0083	–	Derived from Bathymetry	Anderson et al. (2016a)
TRI[a]	-	0.0083	–	Derived from Bathymetry	Wilson et al. (2007)
Roughness	-	0.0083	–	Derived from Bathymetry	Wilson et al. (2007)
Aspect - northness[a]	-	0.0083	–	Derived from Bathymetry	Hogg et al. (2016)
Aspect - eastness[a]	-	0.0083	–	Derived from Bathymetry	Hogg et al. (2016)
Curvature - general[a]	-	0.0083	–	Derived from Bathymetry	Wilson et al. (2007)
Curvature - planar[a]	-	0.0083	–	Derived from Bathymetry	Wilson et al. (2007)
Curvature - profile[a]	-	0.0083	–	Derived from Bathymetry	Wilson et al. (2007)

Table 2.1 continued: Predictor variables tested in MaxEnt model. Source: Brewin et al. (2020).

Environmental variable	Units	Native resolution (o)	Temporal resolution	Source	Reference
Seabed sediment					
Gravel	%	0.05	–	dbSEABED	Jenkins (2019)
Mud	%	0.05	–	dbSEABED	Jenkins (2019)
Sand	%	0.05	–	dbSEABED	Jenkins (2019)
Rock	%	0.05	–	dbSEABED	Jenkins (2019)
Carbonates[a]	%	0.05	–	dbSEABED	Jenkins (2019)
Sand: gravel[a]	-	0.05	–	dbSEABED	Jenkins (2019)
Sand: mud[a]	-	0.05	–	dbSEABED	Jenkins (2019)
Productivity					
SS Chl_a Mean/C.V.[a]	mg m^{-3}	0.04	Monthly	MODIS-A L3 SMI 2002-17	https://oceancolour.gsfc.nasa.gov
Physical water properties					
SST mean/C.V	°C	0.04	Monthly	http://sose.ucscl.edu	Mazloff et al (2010)
Seabed Temp mean/C.V[a]	°C	0.04	Monthly	http://sose.ucscl.edu	Mazloff et al (2010)
Seabed salinity mean/C.V[a]	PSU	0.04	Monthly	http://sose.ucscl.edu	Mazloff et al (2010)
Seabed density mean/C.V[a]	kg m^{-3}	0.04	Monthly	http://sose.ucscl.edu	Mazloff et al (2010)
Seabed current speed mean/C.V[a]	m s^{-1}	0.04	Monthly	http://sose.ucscl.edu	Mazloff et al (2010)
Chemical water properties					
Aragonite saturation state[b]	μmol kg^{-1}	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Dissolved oxygen	μmol kg^{-1}	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Dissolved inorganic carbon	μmol kg^{-1}	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Calcite saturation state	μmol kg^{-1}	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Nitrate	μmol kg^{-1}	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Silicate	μmol kg^{-1}	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Phosphate	μmol kg^{-1}	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Total Alkalinity[a]	μmol kg^{-1}	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)

Full decriptions and full citations are found in Supplementary material S2.

[a] Factors retained after the examination of correlation matrices

[b] Aragonite saturation (Omega A) was used only for AXT and CSS only.

FISHING EFFORT OF LICENCED & HIGH-SEAS FISHERIES

Brewin et al. (2020) gathered line-by-line commercial longline position data from the Falkland Islands Government Fisheries Department electronic logbook database for fishing occurring between January 2012 and December 2016 (N¼42496). Latitude and longitude for the line "setting-start" and "setting-end" positions were used to map each longline set (assuming that the line is set straight). However, speed, position, and bottom topography vary during line setting the line is likely to take a less uniform pattern along the seabed than assumed in modelling. **Global Fishing Watch (GFW)** data were used "to examine fishing effort within the FCZ and on the high-seas adjacent to the FCZ from January 2012 to December 2016. GFW gathers global S-AIS data and processes it using convolutional neural networks to identify fishing vessels and fishing activity (Kroodsma et al., 2018). GFW has a 95% accuracy in predicting vessel type (six classes of fishing vessel and six classes of non-fishing vessel), and of fishing vessels, it predicts fishing activity with >90% accuracy (Kroodsma et al. 2018). The product used in the present study was gridded (1 km^2 resolution) daily hours of fishing. GFW data were filtered for toothfish bottom longline vessels by first, selection of either "drifting longlines" or "fixed gear" records. Records were then further filtered by the Flag States known to fish for toothfish in the region; retained vessel flags are Chile (CHL), Falkland Islands (FLK), South Korea (KOR), and Ukraine (UKR). This second step ensures selection of toothfish bottom-set longline vessels and not pelagic longline fishing vessels from other Flag States targeting other species". The final GFW data set used in Brewin et al. (2020) consisted of 133 297 records for the ABNJ and 21 334 records for the FCZ. Consequently, after assessing and determining the utility of GFW data, Brewin et al. (2020) define fishing footprint "to be the fishing spatial extent as defined by GFW grid squares where longline fishing activity has been estimated in both the licenced and ABNJ fisheries at the native spatial scale of GFW data (1km^2 scale resolution), and fishing effort represented as the effort (total h km^2) across years per grid square". All analyses were performed in R (v3.5.1) and QGIS (v3.4.2) and spatial data were projected in the coordinate system UTM21S for the calculation of areas (km^2).

RESULTS

Indicator taxon occurrence

Brewin et al. (2020) included a total of 1570 presence records of indicator taxa across 18 VME taxa groups in FCZ, with a more limited distribution in the ABNJ (Fig. 2.1). Cnidarian groups were most common in the dataset, particularly the Scleractinia (23.06%), Gorgonacea (15.41%), Alcyonacea (7.90%), and Stylasteridae (7.39%) (Table 2.2), and consequently these and other VME indicator taxa groups with broad spatial coverage and high numbers of records were selected for MaxEnt analysis including: Alcyonacea, Scleractinia, Gorgonacea, Stylasteridae, and Demospongiae. Pennatulacea were also chosen, because this group is a model taxa, indicative of habitats possibly not represented by other groups (Greathead et al., 2014).

Benthic camera imagery collected in the FCZ toothfish fishing grounds indicated a patchiness of VME indicator taxa group distribution (Fig. 2.2), particularly encrusting species found on drop stones (rocky areas on soft sediments). Longline-mounted cameras captured evidence of disturbance by "trotline" longline gear to the seabed. These were indicated by the presence of narrow furrows (20 cm in width) in soft sediments, caused during hauling. Dropline weights may also strike patches of VME indicator taxa attached to hard substrates in areas of soft sediments.

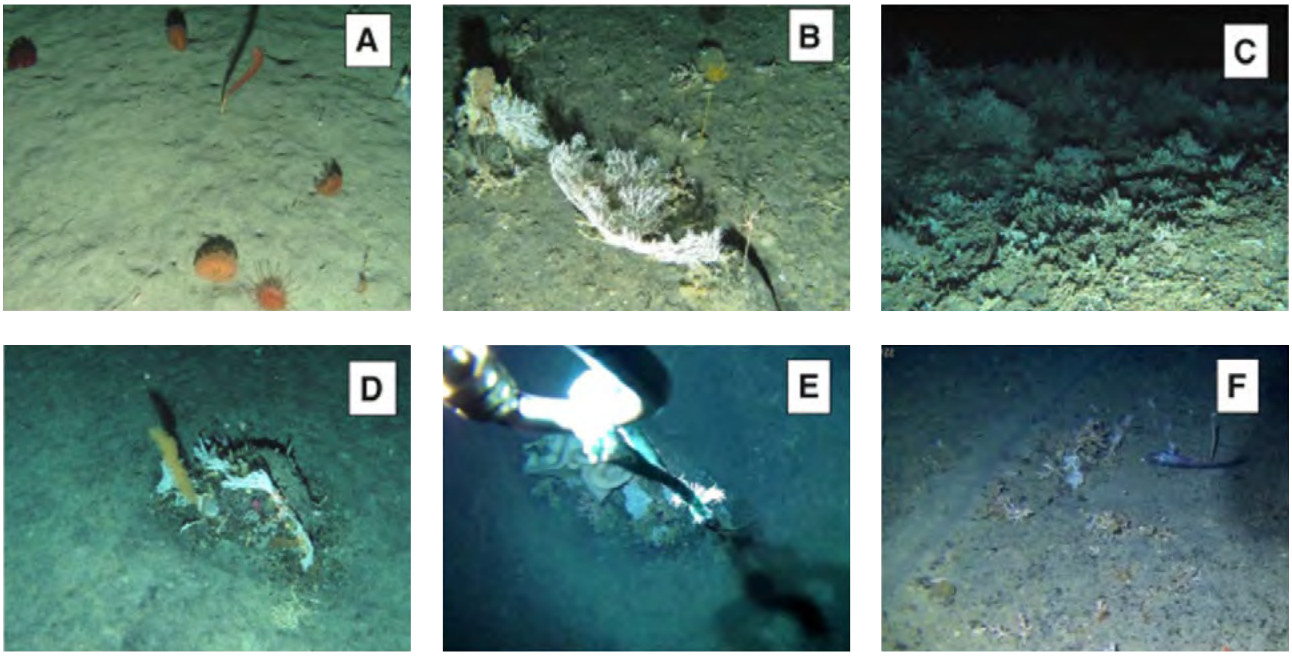


Fig. 2.2: *VME indicator taxa examples showing the range of species and patchiness (a) Soft sediment dominated by sea pens; (b) various coral species and a stalked crinoid; © coral reef-like habitat; (d) VME indicator taxa on rock patches; (e) down-line with weight adjacent to rock patch with large sponge, and (f) Soft-gravel sediment showing furrow caused by the dragging of weight. Track is ~20 cm wide. Source: Brewin et al. (2020)*

MAXENT MODEL PREDICTION

MaxEnt model predicted taxa distributions show that some taxa are widely distributed across the model domain, such as Scleractinia and Demospongiae (Fig. 2.3). In contrast, Brewin et al. (2020) found "the predicted distribution of Pennatulacea is constrained to the western region of the northern flank of the Burdwood Bank". The octocoral (soft) coral group, Alcyonacea predicted habitat is mostly around the northern edge of the FCZ surrounding the Burdwood Bank. Stylasteridae (lace) coral habitat was also well represented along the Burdwood Bank (FCZ) and North Scotia Ridge (ABNJ) but had less probability of occurrence to the north within the FCZ or in adjacent ABNJ.

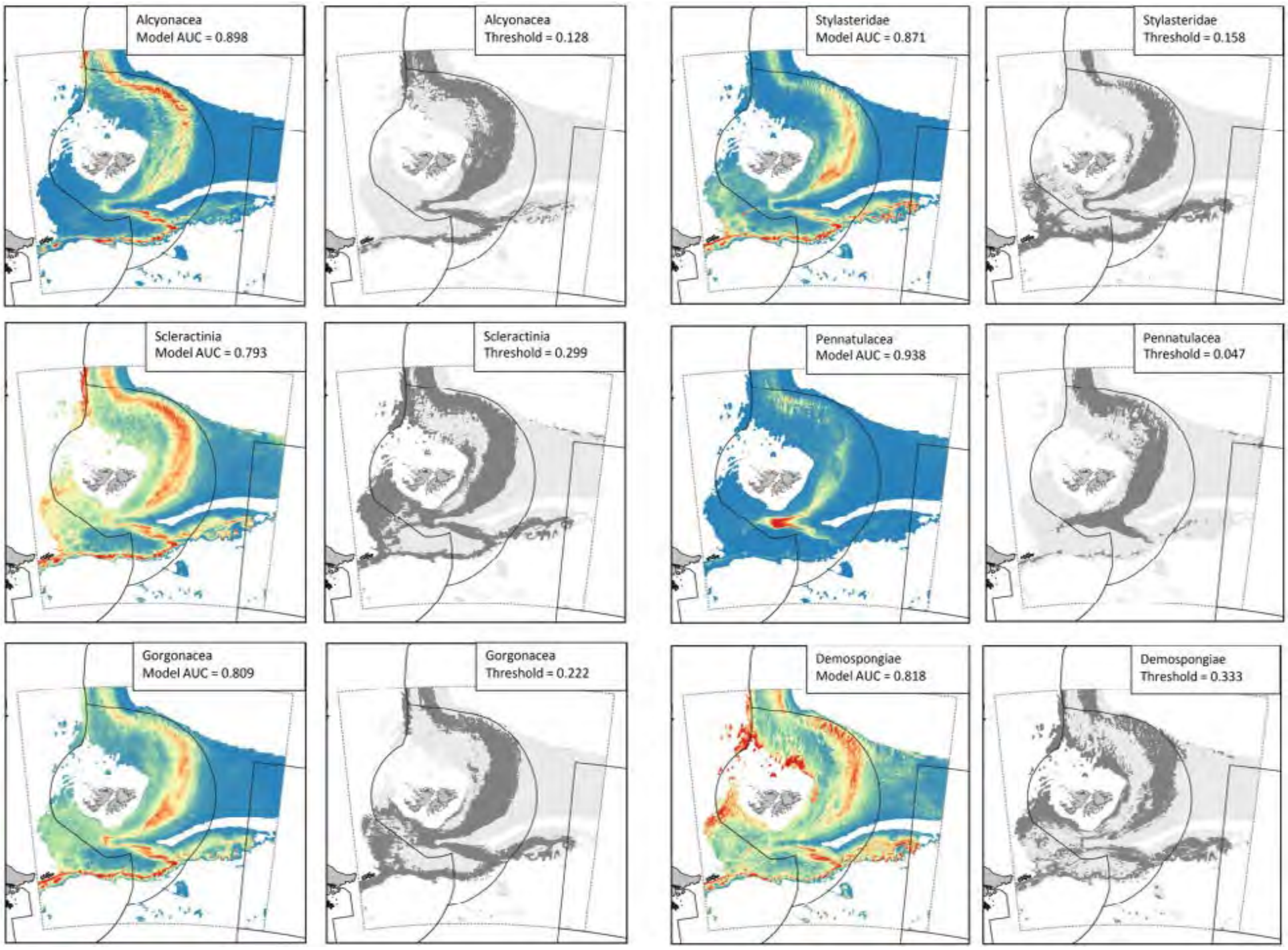


***Fig. 2.3:** Mapped MaxEnt full model (left) and binary (right) predicted distribution shown, including AUC scores, and threshold values. Full model probabilities range between 0 (blue) and 1 (red). Threshold values are either 0 (light grey) or 1 (dark grey). Solid lines are related borders (See Fig. 2.1). Dashed line denotes the model domain. Source: Brewin et al. (2020)*

Table 2.2: VME group occurrences on the Patagonian Shelf from all datasets used. Source: Brewin et al. (2020)

VME taxa	*VME group (CCAMLR)*	*Common name*	*Total occurences*	*Proportion of observations (%)*
Scleractinia	**CSS**	**Stony corals**	**362**	**23.1**
Gorgonacea	**GGW**	**Sea fans, Sea whips**	**242**	**15.4**
Alcyonacea	**AJZ**	**Soft corals**	**124**	**7.9**
Pennatulacea	**NTW**	**Sea pens**	**87**	**5.5**
Anthoathecatae	AZN	Hydroids	47	3.0
Stylasteridae	**AXT**	**Hydrocorals**	**116**	**7.4**
Actiniaria	ATX	Sea anemones	52	3.3
Antipatharia	AQZ	Black corals	3	0.2
Zoantharia	ZOT	Zoanthids	1	0.1
Echinodermata				
Euryalida	QEQ	Basket stars	153	9.7
Cidaroida	CVD	Pencil urchins	41	2.6
Stalked crinoid	CWD	Stalked sea lilies	6	0.4
Porifera				
Demospongiae	**DMO**	**Sponges**	**135**	**8.6**
Hexactinellida	HXY	Glass sponges	34	2.2
Chordata	SSX	Sea squirts	57	3.6
Brachiopoda	BRQ	Lamp shells	25	1.6
Bryozoan	BZN	Lace corals	75	4.8
Annelida	SZS	Polychaets	10	0.6

Brewin et al. (2020) show that "seabed depth had strong predictive power for Gorgonacea and Pennatulacea habitats and a narrow range of depth preference (Table 3, Supplementary material S2). The factors slope, TRI (terrain ruggedness index), and aspect-north were somewhat important in predicting taxa habitat. Sediment variables showed some predictive power, particularly carbonates for Stylasteridae and sand:gravel ratio for Demospongiae. Mean monthly surface productivity (chl_a) and variability were relatively important predictors of all groups. There were mixed levels of importance of mean and C.V. of water physical properties (temperature, salinity, density), although seabed salinity_cv showed a strong inverse relationship with habitat suitability for Pennatulacea (Table 3, Supplementary material S2). Mean seabed current speed and variability predictors were important for all groups except Pennatulacea. Of the chemical properties of water tested, aragonite saturation state was relatively important when used in the models for Scleractinia, Gorgonacea, and Stylasteridae (noting that this variable was not included in models for other groups). Finally, alkalinity was a strong predictor for all groups, in some cases a stronger predictor than depth. Although beyond the scope of this study, a detailed examination of response curves can be done (Supplementary material S2) which will contribute to better describing the environmental envelope of VME indicator taxa groups in the Patagonian Shelf".

Table 2.3: Relative contributions (%) of the environmental variables to predicted habitat suitability of each VME group used. Source: Brewin et al. (2020)

Variable	*Alcyonacea*	*Scleractinia*	*Gorgonacea*	*Stylasteridae*	*Demospongiae*	*Pennatulacea*
Bathymetry	22	34	46.8	26	14.9	43.8
Slope	4.4	4.6	6.3	1.3	0.5	0.2
BPI - broad	1.7	0.4	3	3.5	4.3	0.1
BPI - fine	-	-	-	-	-	-
TRI	8.5	1.2	0.4	2.5	0.8	-
Aspect - northness	7.7	2.9	1.3	0.8	5.4	0.4
Aspect - eastness	1	0.7	1.1	1.9	4.5	0.3
Curvature - general	-	-	-	0.5	0.1	-
Curvature - planar	0.4	-	-	1	-	-
Curvature - profile	-	-	-	-	-	-
Carbonates	0.2	3.3	3.1	11.5	2.4	3.1
Sand: gravel	1.2	0.1	0.5	1.5	11.4	0.2
Sand: mud	0.7	1.1	1.5	2.9	1.8	1
SS Chl_a mean	2.5	4	3.1	1.8	8.5	0.1
SS Chl_a C.V	1.3	4.8	1.7	5	2.4	0.7
Seabed Temp mean	0.4	1	1.6	1.1	3.4	0.3
Seabed Temp C.V	0.7	0.6	0.7	0.3	0.2	0.3
Seabed salinity mean	2.6	1.5	0.7	0.2	1.2	0.6
Seabed salinity C.V	6.6	4.9	5.6	1.1	4.6	27.4
Seabed density mean	-	-	-	-	-	-
Seabed salinity C.V	0.2	0.3	8.3	7.1	0.3	0.1
Seabed current speed mean	4.3	3.7	1.7	2.7	7.3	0.1
Seabed current speed C.V	2.8	3.5	2.2	3.3	5.4	0.1
Aragonite	-	3	2.8	7.8	-	-
Alkalinity	30.7	24.4	7.4	13.5	20.7	21.4

COMPARISON OF FISHED AREA AND VME PREDICTED HABITAT

The total area of fishing footprint determined by Brewin et al. (2020) for both the FCZ and ABNJ is 36 924km^2, and the total footprint of actual fished ground in the ABNJ is almost twice as large as the FCZ (23 928 and 12 997 km^2). Brewin et al. (2020) state that ''within each area, the areas of low effort were relatively similar between the ABNJ and FCZ (15 404 and 11 195 km^2, respectively); however, areas of medium and high effort were four times greater and 13 times greater respectively in the ABNJ compared to the FCZ fishing area (Table 4)''.

The predicted habitat for each VME indicator taxa group within the FCZ is an order of magnitude larger than the predicted habitat in the ABNJ ("low", "medium", or "high" effort of fishing Table 5). Predicted VME habitats are larger in the FCZ, compared to ABNJ but the fishing footprint is similar, this means that the percentage fishing footprint of predicted area of VME indicator taxa was an order of magnitude lower than ABNJ. The total fishing footprint area within predicted habitats was relatively similar for FCZ and ABNJ fisheries for all coral groups. Brewin et al. (2020) state that ''in terms of percentage area the fishing effort in predicted VME habitat areas was also considerably smaller proportionally in the FCZ compared to the ABNJ''.

Table 2.4: Footprint area (km^2) of toothfish (*Dissostichus eleginoides*) fishing effort categorised as low, medium, and high intensity effort for each fishing zone. Source: Brewin et al. (2020)

Effort category	FCZ	ABNJ	Total
Total footprint	12 997	23 928	36 925
Low effort	11 195	11 195	26 599
Med effort	1 665	16 65	8 401
High effort	137	137	1.29

Table 2.5: Total predicted habitat area for taxa groups compared to total fishery footprint, and areas of low, medium and high fishing effort in terms of area (km^2) and percentage of predicted habitat area. Source: Brewin et al. (2020)

VME Group	Predicted Habitat area (km^2)	Fishery footprint within predicted habitat (km^2)	Footprint as % of predicted habitat	Low effort fishing area (km^2)	Low effort fishing as % of predicted habitat	Medium effort fishing area (km^2)	Medium effort fishing as % of predicted habitat	High effort fishing area (km^2)	High effort fishing as % of predicted habitat
Footprint in the FCZ									
Alcyonacea	140 814	11 212	7.96	9 687	6.88	1 404	1.00	121	0.09
Scleractinia	179 299	12 001	6.69	10 335	5.76	1 540	0.86	126	0.07
Gorgonacea	155 834	12 374	7.94	10 657	6.84	1 591	1.02	127	0.08
Stylasteridae	115 328	11 329	9.82	9 838	8.53	1 372	1.19	119	0.10
Pennatulacea	113 850	9 102	7.99	7 918	6.96	1 097	0.96	87	0.08
Demospongiae	159 248	10 266	6.45	8 852	5.56	1 296	0.81	118	0.07
Footprint in the ABNJ									
Alcyonacea	18 080	7 882	43.59	4 853	26.84	2 400	13.27	629	3.48
Scleractinia	26 599	12 676	47.66	7 452	28.02	4 118	15.48	1 106	4.16
Gorgonacea	24 450	13 667	55.90	7 889	32.26	4 520	18.49	1 258	5.14
Stylasteridae	23 496	14 565	61.99	8 602	36.61	4 688	19.95	1 276	5.43
Pennatulacea	12 110	3 950	32.62	2 260	18.66	1 348	11.13	342	2.82
Demospongiae	36 560	17 859	48.85	10 881	29.76	5 492	15.02	1 486	4.06

DISCUSSION

The results of Brewin et al. (2020) support global concern over the absence of sustainable management and practice in relation to VMEs in ABNJ areas world-wide (e.g., Rowden et al. 2019; Wright et al. 2019). The Falkland Islands is an exemplar for VME habitats, situated in areas directly adjacent to unmanaged fisheries. Falkland Islands fisheries management encompasses the western VME habitat used in this study, and CCAMLR encompasses the eastern area. Whilst the adjacent area lacks a management authority and is subject to incidents of illegal unreported and unregulated (IUU) fishing efforts. This lack of management could undermine the sustainability of the Falkland Islands fisheries, and places extra emphasis on a transition towards cross-boundary harmonisation of fisheries management, considered best-practice. However, minimal attention has been given to what this process would entail for targeted fish stocks such as toothfish for VMEs (but see CCAMLR Resolution 10/XII for member State harmonisation between the Convention areas and adjacent RMFO/A).


Ventral (bottom) view of a gastropod shell, possibly *Belaturricula sp.*, from the Burdwood Bank

The Brewin et al. (2020) analysis established the first realistic estimate for fishing effort on the ABNJ. This work, combined with recent work in the Falklands toothfish fishery (Farrugia and Keningale, 2018), and internationally (Sharp, 2010; Welsford et al. 2014), has suggested that the impact of longline fishing on the seabed may be spatially limited to 10–100 s of metres in the immediate vicinity of the longline. Brewin et al. (2020) state that this level of detailed analysis is only possible in a managed fisheries context where there is ''reporting of gear type, effort, line-by-line positional data, scientific observer reports and coordinated research investigations''. Unregulated fleets, by nature of being unregulated, do not have reporting obligations. As a consequence, the use of model/proxy data such as GFW is necessary. However, although the global availability of these data is advantageous, these data are limited in other ways.

Firstly, satellite—Automatic Identification System (S-AIS) is a legal requirement for all vessels of 300 gross tonnes or larger. This differentiation includes bottom-set toothfish longline vessels. However, as part of the International Maritime Organisation (IMO) Safety of Life At Sea Treaty (SOLAS Treaty, Chapter V, www.imo.org), legal enforcement is extremely variable among reporting organisations and/or Flag States (Dunn et al., 2018). Particularly so for ABNJs. This means that GFW data provides a conservative estimate of fishing effort. Brewin et al. (2020) outline that there are also other associated errors to consider such as ''signal loss due to signal traffic, or gaps in the record due to satellite overpass times''. However, they ascertain, that In terms of GFW data itself, error rates for GFW predictions are low (Kroodsma et al. 2018)'', in order to ground-truth these data, specific fisheries should closely examine GFW outputs for real-world accuracy and anomalous predictions. In the Brewin et al. (2020) study, there were what they term ''systematic misclassifications related to the detection of either benthic or pelagic longlines, and longline vessels and jigging vessels. In the Patagonian Shelf region, these are easily accounted for by examining vessel Flag, as well as the region being fished (i.e. the combined constraints of bathymetric distribution of targeted toothfish and territorial boundaries)''.

Secondly, the Brewin et al. (2020) method ''assumes that fishing gear used on the high-seas is similarly configured and deployed to vessels in the FCZ. A like-for-like metric of fishing effort was established in this study for licenced fishing within the FCZ. However, the assumption that all vessels in the ABNJ are using trotline systems, set at similar line lengths, deployed by vessels of similar capacity, and with similar judgements for choice of fishing area as vessels in the FCZ may be at best, only partly correct. Indeed, "Spanish line" and "auto-line" longline systems are commonly used elsewhere (Collins et al. 2010). Trotline and Spanish line systems are similar in that they may have limited contact with the seabed with only drop-line weights meeting the seabed (although this is unlikely), whilst auto-line systems may completely lie on the seabed, and there are other variations of these gear configurations presently used in the fishery''.

Brewin et al. (2020) suggest that estimates of exposure to the high-seas seabed are likely to be more uncertain and conservative than their model suggests and ''a more detailed examination of the relative impact of different longline gear types would be useful for better understanding the impacts of longline fishing on VMEs particularly in areas where mixed gear types are used (e.g. CCAMLR waters) as is most likely the case in the ABNJ adjacent to the FCZ''.


Aboral (top) view of an unidentified brittle star from the Burdwood Bank

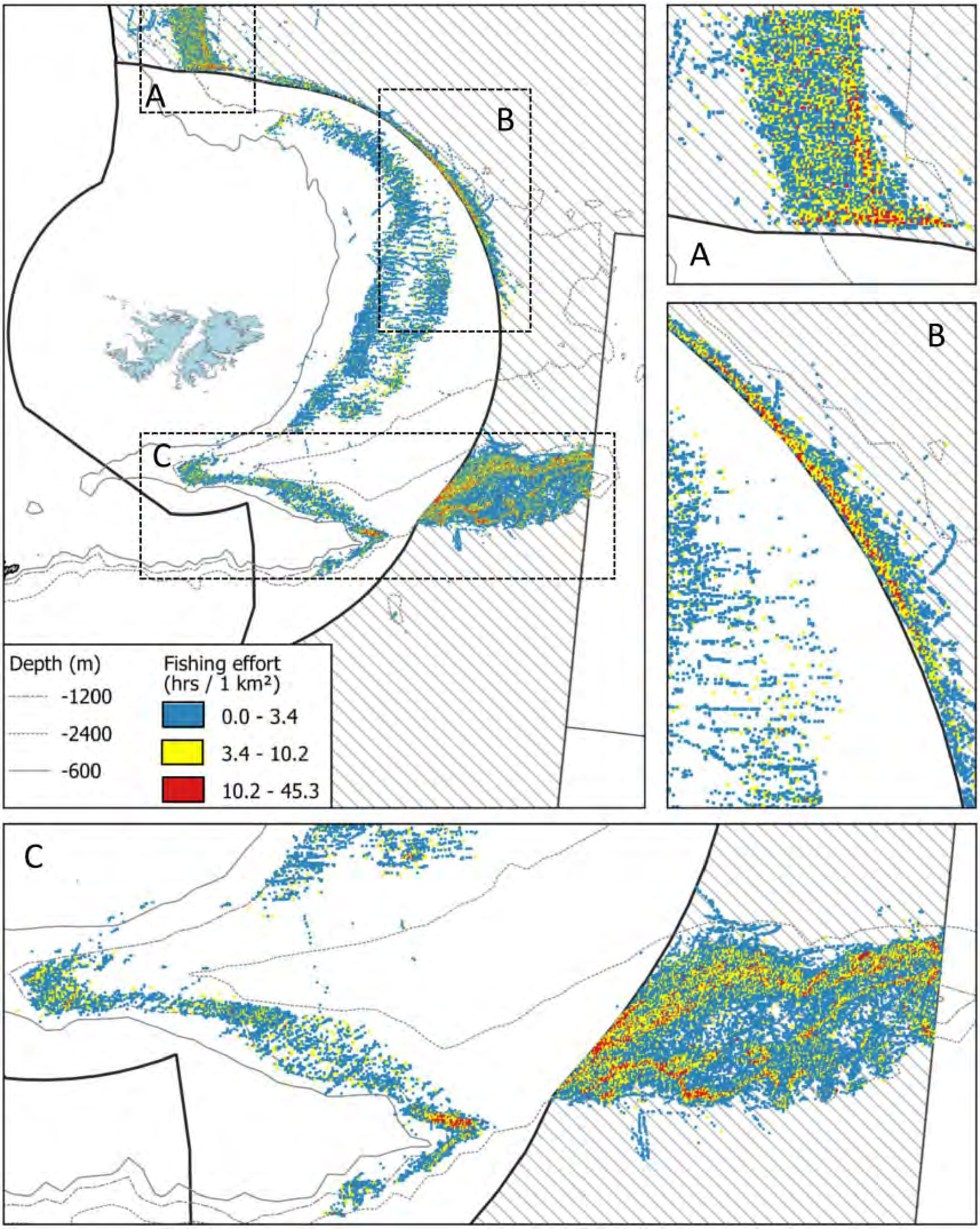


Fig. 2.4: *Fishing effort with the FCZ and in ABNJ areas (hrs/km^2) using GFW effort data (2012 - 2016). Also shown are the 600- and 2400- m depth contours, the FCZ and CCAMLR borders, and ABNJ (shaded) for reference. Source: Brewin et al. (2020)*

Brewin et al. (2020) predicted habitat suitability maps suggest that most VME taxa groups are widely distributed throughout much of the FCZ (Fig. 3). This work demonstrates the continuity of habitat types into ABNJ. Additionally, locations of individual sampling (Fig. 1) were found across a wide range of habitat suitability probabilities. These predicted distributions of VME indicator taxa varied in their range. For example, Sponges were widely distributed, whilst sea pens had a narrow distribution. However, these taxa have been grouped and as a consequence do not provide species level distribution knowledge, and only an aggregate idea of niche partitioning on the seafloor. For example, sponges occupy multiple habitat types, with a wide range of morphologies, life history characteristics and modes of reproduction, all of which could influence their distribution (e.g., Rooper et al. 2017). Whilst sea pens have a comparatively narrow range, restricted to the North-western flank of the Burdwood Bank. Sea pens are the only octocoral group known to occupy soft muddy or sandy sediments (Greathead et al. 2014). Brewin et al. (2020) suggest this narrow niche envelope and consequently, aggregations of sea pen species into a taxa group may have less impact on their habitat prediction. Therefore, in the case of sea pens, the results of Brewin et al. (2020) suggested further investigation into sea pen biology and ecology in the Falklands. An action that is currently in progress through the work of Dr. Tabitha Pearman at SAERI. Tabitha's work will lead to a greater understanding of sea pens as indicators of vulnerable habitat (OSPAR, 2010) as well as providing more information on their potentially significant ecological role in supporting biodiversity and fisheries (Greathead et al. 2014). This work in combination with improved species identifications is ongoing through the research of Dr Narissa Bax at SAERI for coral groups such as scleractinia and Stylasteridae, in combination with collaborative taxonomic networks for Burdwood Bank specimens.

It is recommended that a combined approach is taken across all VME taxa to better elucidate the physical/biological drivers and better define the fundamental niche envelopes for each group/species where possible to do so (e.g., Davies and Guinotte, 2011). Brewin et al. (2020) state that ''whilst model performance was found to be relatively good (as assessed by the AUC model fit score), predicted habitat could be further constrained (and model fit improved) through improved taxonomic resolution of species identification as well as extending sampling throughout the model domain; AUC scores can be lower when presence data do not span the full spatial extent of the region of interest (Fourcade et al. 2014), and this may be the case in the present study''. Additional benthic invertebrate sampling and collaboration with taxonomists will improve this aspect of the work. In addition, Brewin et al. (2020) clarify that the ''resolution of predictor variables can have an impact on predicted habitat distribution. For example, Ross and Howell (2012) suggested that the coarse resolution of GEBCO (www.gebco.net) bathymetry used in their study was likely to have produced an overestimation of habitat distribution in the NE Atlantic deep-sea VMEs. Similarly, in the present study, limited benthic video evidence revealed significant patchiness of hard substrates (Fig. 2) that may not be well resolved in seabed sediment and terrain metrics; such patchiness would likely impact the true VME taxa distribution and density in the case of encrusting taxa such as the Gorgonacea or Stylasteridae''.

Brewin et al. (2020) suggest that ''higher-resolution empirical data in all predictor variables would facilitate better sensitivity testing of threshold values when producing binary prediction maps for management decision-making'' (Merow et al., 2013, Anderson et al. 2016a), to remove bias (Guillaumot et al. 2018), and validade the various model assumptions. However, these data can offer their own intrinsic biases to model output and Brewin et al. (2020) recommend that future modelling efforts might consider ensemble approaches (Robert et al., 2016; Rowden et al. 2019).

A discontinuity of management for VMEs could have detrimental consequences for the resilience and/or recovery of locally isolated VME taxa populations (Thrush et al. 2013). This is particularly so, where there are impacts on local recruitment rates as well as connectivity of recruitment throughout the region. VME taxon form multiple 'metacommunities', these communities are maintained by the way of dispersal via intra- and interspecies ecological processes that modulate larval dispersal connectivity (e.g., Kenchington et al. 2019). Brewin et al. (2020) use the example of meanfield flow. Meanfield flow ''south of the Patagonian Shelf is characterised by eastward flow along the Burdwood Bank and North Scotia Ridge, with a northward branch crossing the North Scotia Ridge onto the eastern Patagonian Shelf (Fig. 2.1) forming the Falklands Current (Arhan et al., 2002)''. In a broad sense, this connection of water flow suggests that VME populations in the west might form source populations for the eastern and northern populations, exchanging dispersive larvae overtime. Meaning that ''VME taxa assemblages in the ABNJ may be supported by those found in the FCZ and further west but could have reduced resilience/recovery potential to the east of the ABNJ (e.g., in CCAMLR waters)''. This has important implications, and without improved knowledge on the reproductive and larval biology, and dispersal potential of deep-sea VME species (Watling et al. 2011; Hila´rio et al. 2015) the scales of species' dispersal is impossible to validate (Kinlan et al. 2005). Brewin et al. (2020) suggest, that ''in the absence of knowledge of true local recruitment processes or regional dispersal dynamics of VME taxa, and assuming that deep-sea VME assemblages have limited recovery potential (Clark et al. 2016), precautionary management strategies based on predicted habitat distributions will mitigate potential impacts of longline fishing and promote post-impact recovery of VMEs in managed and ABNJ fisheries. Future modelling of VME taxa distribution could be enhanced by integrating such ecological processes in the prediction algorithm where possible (Staniczenko et al. 2017)''.

Conclusion

Brewin et al. (2020) showed that predicted habitats of VME indicator taxa "straddle" different management regimes, in a similar way to how fish stock also straddles different geographies. The impact of discontinuous management is unknown, and there is a serious need for the better understanding of both VME indicator taxa distributions and the impacts of fishing when VME habitats cross contrasting management and conservation regimes (or in some instances a lack of management). Until this time, an interim precautionary management approach is recommended. Whilst some recent work highlights improved fisheries management (Worm et al. 2009; Halpern et al. 2015; Amoroso et al. 2018), unregulated ABNJ fishing could compromise any benefits gained from these initiatives. Brewin et al. (2020) suggest that new ''ABNJ conservation initiatives such as the high-seas treaty targeting Biodiversity Beyond National Jurisdictions (BBNJ) (UNGA, 2015) may require such harmonisation for VMEs''. Furthermore, improved knowledge could be gained through the establishment of an RFMO/A-styled multilateral agreement in ABNJ. This approach would pave the way for a ''regional cohesive view of VME distribution and fishing impact''. Underpinning this approach are conservation measures such as, regulated scientific and industry reporting of effort, and the regulated use of electronic vessel monitoring (e.g., S-AIS). These data can then be used by managers and policymakers (Ardron et al., 2014; Wright et al. 2019), to support the development of area-based management tools (ABMT) across a contiguous managed area that includes ABNJ fisheries that extend into the Scotia arc and the edge of the SMZ.

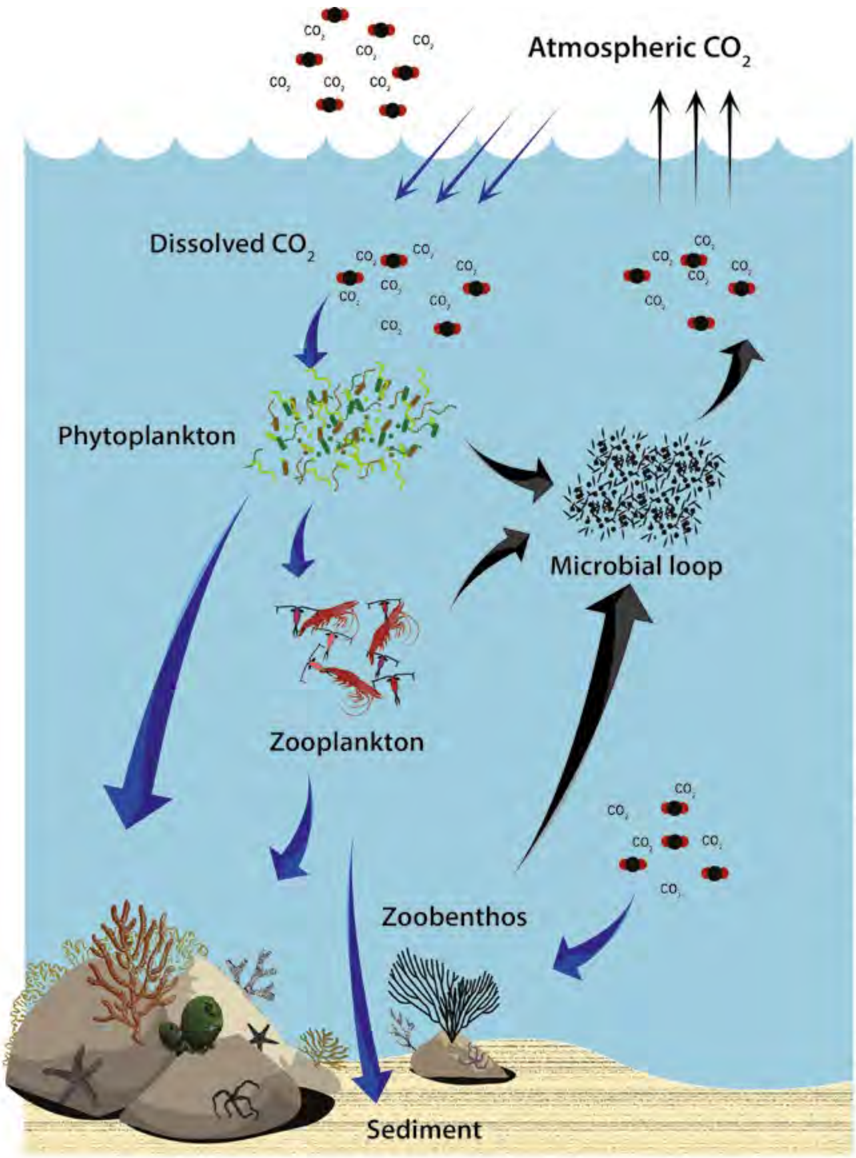
Data archiving

All Falkland Islands Government data used in Brewin et al., (2020) are available through the South Atlantic Environmental Research Institute (SAERI) IMG-GIS Data Centre. Data request forms and data management policies can be found through the website **www.south-atlantic-research.org/research/data-science**. All other data are publicly available and web-distributed through cited institutions.

Acutiserolis sp. from the Burdwood Bank

2.2 OFFSHORE: BLUE CARBON AND VULNERABLE MARINE ECOSYSTEMS ON THE BURDWOOD BANK

In 2018 and 2019 SAERI partnered with the British Antarctic Survey (BAS) on Darwin Initiative grant funded work to collect data on the proposed southern Burdwood Bank MMA during two voyages on the RRS James Clark Ross (JR18003 and JR19002). This section focuses on preliminary research to understand the benthic community using Shelf-Underwater Camera System (SUCS) imagery and (where possible) data from collected specimens in the context of VMEs and seafloor blue carbon.



Capture
phytoplankton takes up inorganic carbon, converting it to organic carbon - energy

Storage
captured organic carbon is held in living tissue and cascaded through the food chain

Microbial action
much of the organic carbon is released back into the ocean as both organic and inorganic carbon due to cellular destruction in the microbial loop

Bentho-pelagic coupling
trophic interactions channel organic carbon directly or indirectly to the animals on the sea

Immobilisation
organic carbon, through trophic cascade, and inorganic carbon, due to direct absorption to make hard parts, held within a matrix such as shell or skeleton. Carbon unlikely to easily move into microbial loop so held for long periods of time (months - years)

Burial
a proportion of organic tissue and inorganic shells and skeletons are buried in sediment

Sequestration
organic and inorganic carbon that has been buried and avoids decomposition has effectively been removed from the carbon cycle for many years (hunderds - thousands)

Fig. 2.5: *Overview of the carbon cycle as it relates to seafloor blue carbon burial and sequestration. Image credit: Camille Moreau and Chester Sands, adapted from Gogarty et al. (2020).*

WHAT IS CARBON CAPTURE?

Carbon capture occurs in surface waters as primary producers (e.g. phytoplankton) use sunlight to fix atmospheric inorganic carbon to organic carbon, locking away CO_2 for variable time periods. Long-term sequestration for 100s to 1000s of years only occurs when animals die and they are buried below the anoxic layer of the seafloor.

WHAT IS CARBON STORAGE?

Carbon storage is temporary, lasting only months, but in some cases years. CO_2 is still active in the ocean carbon cycle and held in the living tissue of marine life, cascading through the food chain.

WHAT HAPPENS TO CO_2 IN THE MICROBIAL LOOP?

Organic carbon fuels marine food webs, transporting CO_2 through the process of respiration and releasing it back into the water column. Then, when cells and organisms die, the dead organic material is degraded by bacteria in the microbial loop and partly respired to CO_2. If this release of carbon is greater than the uptake of carbon by phytoplankton, CO_2 outgasses back into the atmosphere.

WHAT IS CARBON IMMOBILISATION?

Immobilisation occurs in the skeletons of living animals, particularly calcifying animals like corals, bryozoans, brittle stars etc with a carbonate skeleton, where it can be retained for years, or possibly centuries.

KEY TAKE-AWAY POINTS:

- The Burdwood Bank NMNR hosts high benthic biodiversity and there are minimal known impacts.
- This is a first-level baseline assessment of blue carbon potential on the Burdwood Bank, including the NMNR. Future work could also include the SMZ.
- Preliminary research suggests the Burdwood Bank hosts high carbon storage and high sequestration potential, particularly on the shallow plateau region within the proposed MMA NMNR boundary.
- Newly identified carbon rich biodiversity habitats including abundant stylasterid and scleractinian coral assemblages add to the conservation significance of the Burdwood Bank seafloor.
- Cold water corals are not currently recognised as blue carbon habitats, as they re-emit some CO_2 when building their $CaCO_3$ skeletons. However, their importance as ecosystem engineers and sediment creators, and their vulnerability to climate change mean a focus on maintaining ecosystem function at the site of sequestration, where it is most crucial to long-term climate mitigation, includes conservation of all VME indicator taxa (corals, sponges, bryozoans etc.) and the ecosystem services a biodiverse seafloor habitat can provide.
- Much of the organic carbon stored on the proposed Burdwood Bank MMA could result in long-term sequestration, so long as the seafloor is undisturbed, and VME habitats persist in the face of other threats (such as climate change).
- In the near-term, work to understand VME and ecosystem service frameworks that include blue carbon would benefit greatly from an improved understanding of seafloor topography (e.g. multibeam data).
- Ongoing work includes; efforts to identify specimens to lower taxonomic levels, including the descriptions of new species. There are also efforts to provide the first Vulnerable Marine Ecosystem (VME) indicator taxa guide for the South West Atlantic. These efforts are partnered with global networks aimed at understanding the role of seafloor blue carbon in the carbon cycle, and how this important ecosystem service might change in response to climate change.
- In the pelagic and demersal zones, the quantification of community dynamics, including fish and squid, has been hindered by a lack of standardised sampling techniques. Research presented herein, utilises the standardisation of vessel used and gear deployed to enable a more rigorous analysis of the biogeography of the Burdwood Bank (and the southern Patagonian Shelf) than past studies.
- The pelagic/demersal biological diversity of fish and squid on the Burwood Bank, compared to other parts of the Falkland Islands and High Seas area to the north of the Falkland Islands Conservations Zones, is high.
- Recognition of the Burdwood Bank as globally unique is building across the literature for multiple VME indicator taxa, the inclusion of fish and squid community dynamics into the mix, along with data on the migration of marine higher predators means that the Burdwood Bank could theoretically be described as a province in and of itself - highlighting just how important it is to protect and inform conservation management and insure the sustainability of not only commercially viable fish stocks into the future, but an entire globally important ecosystem.

ABSTRACT:

The Burdwood Bank is a shallow sub-merged plateau region (~50 - 150m), surrounded by the deep sea (>200m), geographically positioned to the South of the Falkland Islands and to the East of the Patagonian shelf. Currently our capacity to define baselines from which to measure change and understand ecosystems at relevant spatial and temporal scales, especially at deeper depths, is constrained. However, despite limitations, the proposed Burdwood Bank Marine Managed Area (MMA) NMNR and SMZ offers a holistic conservation tool, and allows for future scientific monitoring plans for the changing physical parameters (e.g., increasing temperatures and shifting circulation patterns), biogeochemical states (e.g., organism carbon uptake, storage, sequestration and acidification), and ecosystem condition (loss of biodiversity, its functions and services). As researchers, policy makers, and society grapple with the complex suite of threats from decreasing marine resource availability, climate change, ocean acidification and the possible redistribution of species poleward and into deeper depths - locally adapted Marine Protected Areas (MPAs) are seen as a key mitigation strategy. The proposed Burdwood Bank MMA boundary (including the NMNR and SMZ) could encompass up to 10.74% of the Falkland Islands Conservation Zones (FCZ), across depths to 3,000 metres over an area of 46,831 km^2.

This chapter discusses the conservation significance of seafloor communities on the Burdwood Bank and an emerging basis for blue carbon research on the seafloor. Blue carbon is broadly defined as the CO_2 absorbed from the atmosphere by marine ecosystems, which is ultimately sequestered for 100s to 1000s of years. We undertake and present preliminary research, which suggests that the Burdwood Bank hosts high carbon sequestration potential. Newly identified carbon rich biodiversity habitats including abundant Stylasteridae (lace) and scleractinian (cup) coral assemblages add to the conservation significance of this region. Such communities are hypothesised to be particularly vulnerable to physical disturbance, exemplifying their designation as VME indicator taxa. We identify opportunities for future research, framed around two important conservation frameworks 1) Vulnerable Marine Ecosystems (VMEs), and 2) Ecosystem services such as blue carbon. Because a focus on maintaining ecosystem function at the site of sequestration, where it is most crucial to long-term climate mitigation, also includes conservation of VME indicator taxa (such as corals) and the ecosystem services a biodiverse seafloor habitat can provide.

The aim of this section is to provide an overview of VME communities on the Burwood Bank and explore the potential for carbon sequestration on the seafloor blue carbon. This is a synopsis of part of the work that is being prepared for submission to a scientific journal.

INTRODUCTION

The contributions of marine biodiversity to human society are many, these contributions range from climate regulation, to the emotional wellbeing attributed to communities that live on, or near coastal environments. These important contributions are classified under the term ecosystem services, the services that nature provides to humanity (MEA 2005). In offshore environments like the Burdwood Bank, and the deep-sea, these ecosystem services are less immediately obvious to the people and communities which rely on them than the coasts and islands they know and value (Bormpoudakis et al. 2019). The Falkland Islands is heavily reliant on fisheries within its Exclusive Economic Zone (EEZ) (Brewin et al. 2020), supporting fishing licences to foreign fleets and a significant income for the Falkland Islands national accounts.

The ocean and its biological communities and habitats are a sink for carbon dioxide, buffering atmospheric concentrations and humanity against the worst impacts of climate change by absorbing more than 27 percent of Earth's excess carbon dioxide (Laffoley et al. 2021). This important role of the marine environment in the carbon cycle is becoming increasingly relevant in conservation policy due to the significance of healthy marine habitats in carbon storage and sequestration, termed 'blue carbon' (the CO_2 sequestered by ocean habitats) (Barnes et al. 2018a, 2018b, 2021). Mangroves, seagrasses and saltmarshes are commonly recognised as important blue carbon habitats, because they store carbon like trees and are a source of carbon emissions if degraded or destroyed (an analogy that is relatable to terrestrial deforestation). However, these, mostly tropical habitats, are very small in area and in decline (Smith et al. 2022). Other environments such as fjords, kelp forests and seafloor biodiversity, also play important, but little recognized, roles in climate change mitigation. Despite their relevance, Southern Hemisphere cold-water ecosystems remain poorly incorporated in global blue carbon networks and databases. For example, The Coastal Carbon Atlas's most southerly record is in New Zealand, due to a lack of quantifiable data and the many unknowns in terms of latency and long-term carbon sequestration in colder environments.

In locations like the Burdwood Bank, which are expansive and difficult to access, very little is known about what proportion of organic matter is sequestered long-term. Long-term sequestration potential matters, because the portion of carbon locked away in seafloor sediments is removed from the carbon cycle for upwards of thousands of years. In adjacent Antarctic ecosystems, the capacity for this benthic carbon storage and sequestration Antarctic blue carbon appears to be increasing, driven by longer phytoplankton blooms caused by marine ice losses. The Burdwood Bank provides an important comparative test-case in an ecosystem with similar faunal linkages located in an ice-free zone.

Vulnerable Marine Ecosystems framework

Remote, submerged plateau and shelf locations like the Burdwood Bank are characteristic of Vulnerable Marine Ecosystems (VMEs); isolated areas of high biodiversity and productivity (Parker and Bowden, 2010). A VME designated under the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), based on precautionary principles for sustainable fisheries, recognises that the conservation of these habitats and their dependent ecosystems is crucial to the maintenance of biodiversity. Seafloor ecosystems tend to be shaped by long-lived, slow growing organisms with limited dispersal capacity and unique evolutionary histories and population patterns consistent with endemism and specific niche adaptations (Brasier et al. 2021). Such communities are hypothesised to be particularly vulnerable to the effects of environmental change and especially bottom contact physical disturbances, and their susceptibility to destructive fishing techniques exemplifies the term VME (Parker and Bowden, 2010). The vulnerability of deep-sea communities, habitats and ecosystems is further increased by the multiple gaps in our understanding of their biology, ecology and distribution, the compounding threats to their persistence, such as ocean acidification (Figuerola et al. 2021), and the sampling difficulties innate to remote deep-sea and polar science (Brasier et al., 2021). Consequently, we know very little about these environments and animals, such as how they reproduce and disperse, how they grow and colonise new habitats and how they might respond to future changes.

Examples of Vulnerable Marine Ecosystems indicator taxa on the Burdwood Bank

The Burdwood Bank is believed to host high VME benthic biodiversity (Schejter and Mariano, 2021), and cold water corals are abundant (Schejter et al. 2020), including species such as the scleractinian species *Bathelia candida* (Cairns and Polonio, 2013), and the Stylasteridae coral genera *Stylaster, Cheiloporidion and Conopora* which form field-like aggregations (Bax and Cairns, 2014). Surveys of the Burdwood Bank and Falkland Islands Outer Conservation Zone (FOCZ), extending 200 miles from coastal baselines, have identified a number of rare and unusual benthic communities such as structurally complex 'mini-coral gardens'. These gardens are formed by Stylasteridae species *Stylaster densicaulis* and *Conopora verrucosa* (Bax and Cairns, 2014), gorgonian (Primnoidae) coral species and other invertebrate fauna such as sponges and bryozoans (unpublished data). These corals are known as VME indicator taxa, they are habitat forming, providing the Burdwood Banks ecological framework and supporting healthy ecosystem functions.

In adjacent geographies, the documentation of field-like aggregations of deep-sea Stylasteridae corals across the Patagonian shelf and Falkland Islands plateau (Bax and Cairns, 2014, and Bax unpublished data), combined with the high incidence of scleractinian coral and octocoral collections (Schejter et al., 2016, Schejter et al., 2021) during benthic surveys on the western Burdwood Bank, highlights their conservation importance. Complementary research in the zone between the Falklands and the West Antarctic Peninsula have established that corals have lived on the Burdwood Bank for 100,000s of years, with population growth responding to global and regional climate change including warming and changes in the global carbon cycle (Burke and Robinson, 2012). This historic perspective allows scientists to interpret changes in the modern environment against a reliable background state, and clearly illustrates the fragility of ancient comparatively in-tact ecosystems like the Burdwood Bank to extractive uses which disturb and compromise their persistence. It is important that these productive and thriving seafloor communities persist, because beyond any commercial value, they provide invaluable global ecosystem services and host some of Earth's oldest, most intact and well-functioning ecosystems (Burke and Robinson, 2012, Bax et al., 2021, Barnes et al., 2021).

For example, corals are considered important for cycling nutrients, providing the framework on which other animals rely and for their role in carbon sequestration, including the large stock reserves of carbonate accumulated within gravel and meiofaunal (small benthic invertebrate) habitats. Cold water corals are not recognised as blue carbon habitats currently, as they emit marginally more CO_2 than they store during $CaCO_3$ accretion to build their skeletons. However, their importance as ecosystem engineers and sediment creators, and their vulnerability to climate change mean a focus on maintaining ecosystem function at the site of sequestration, where it is most crucial to long-term climate mitigation, includes conservation of VME taxa (such as corals, sponges, bryozoans etc.) and the ecosystem services a biodiverse seafloor habitat can provide (Bax et al., in review). Given that multiple carbon-rich taxa sequester carbon in sediments the Burdwood Bank could provide a valuable ecosystem service of carbon capture, storage and maybe long-term sequestration. Such roles are not unusual for VMEs at this latitude. Biota on continental shelves at high southern latitudes are very effective at sequestering carbon and unlike other carbon sinks, they are increasing with climate change in some locations (e.g., in Antarctica Barnes et al 2016, 2018, Bax et al., 2021). Such a rare and extensive (in area) negative feedback on climate is extremely valuable in terms of social carbon costs (the cost it would take to capture the CO_2 at the source) – a cost that ongoing scientific work on the Burdwood Bank aims to quantify.

Benthic blue carbon an ecosystem services framework for conservation on the Burdwood Bank

The identification and retention of existing areas of biodiverse carbon-rich marine habitat both reduces restoration costs and prevents the loss of important existing biodiversity and carbon stores. The global recommendations of COP26 in November

2021 noted that 'Marine ecosystems are also recognised as "carbon sinks" in Article 21 of the final decision, emphasising the importance of the protection, conservation and restoration of terrestrial and marine ecosystems in the reduction of greenhouse gas emissions (IETA and the University of Maryland, 2021). These global recommendations pave the way for carbon credits linked to blue carbon and marine biodiversity conservation management in the future. Momentum is therefore growing for robust blue carbon research to facilitate policy-integration and inform accurate carbon accounting. Such research incentivizes blue carbon habitats to be managed, created, or restored as a 'nature-based solution' to climate change. However, the data gaps common to remote, highly biodiverse, but funding-limited locations, hinder meaningful progress on the ground. Restoration and creation of habitats will be vital. However, identifying and retaining existing areas of biodiverse carbon-rich habitat must be a main priority. This step will both reduce restoration costs and prevent the loss of existing biodiversity and carbon stores.

Locations like the Falkland Islands fit these criteria and provide a rare geographic testing ground for blue carbon management planning. In this manner, research on the Falkland Islands seafloor can inform long-term ecosystem-based management and synergistically protect both unique biodiversity and inform the Nature-based solutions they provide. The Burdwood Bank marks the Eastern side of the Southern continental shelf limit, and the world's strongest current, the Antarctic Circumpolar Current, separates it from Antarctica (Fig. 2.6). Thus, the Burdwood Bank is an obvious location to monitor climate-mediated change (e.g. Barnes et al. 2018b). It is also a critical time for marine and coastal management in the Falkland Islands. Proposed Marine Managed Areas (MMAs), which align with international criteria for Marine Protected Areas (MPAs). Understanding key ecosystem services in the Falkland Islands (the services provided to people by nature) (Bayley et al. 2021) and information like the location, extent, and condition of broadscale habitat types, will be critical in understanding processes such as carbon sequestration pathways and capacity. Strategic and adaptive planning such as this will help towards retaining biodiversity, maintaining sustainable fisheries and preserving the ongoing benefits of biodiversity for future generations.


Isopod, possibly *Aega falklandica*, from the Burdwood Bank

METHODOLOGICAL OVERVIEW OF RESEARCH TO DATE

Ecological setting

The Falkland Islands is in a unique geographical position on a productive region of the Patagonian Shelf Large Marine Ecosystem (LME) (Marrari et al. 2017). The southern flank of this shelf connects to Tierra del Fuego in the west and the Burdwood Bank south of the Falkland Islands (Fig. 2.6.), which in turn connects to the North Scotia Ridge, and along the Scotia Arc, continuing eastward eventually reaching the Sub-Antarctic island of South Georgia. The eastward flowing Antarctic Circumpolar Current (ACC) water branches to the north at the Burdwood Bank forming the Falklands Current, whilst the main ACC flows east along the North Scotia Ridge. At the Burdwood Bank the ACC branches west (Arhan et al. 2002). There are minimal descriptions of biodiversity assemblages in the region. The notable exceptions are work conducted west of the Burdwood Bank in the Argentinean EEZ where the Namuncura´ Marine Protected Area was established in 2004 (Schejter et al., 2016, 2021), at shallow (200 m) depths. And on the eastern side of the Burdwood Bank, Brewin et al., (2020) assessed VME impacts from 600 and 1800 m depths (and these data were used to inform depths up to 300m). This chapter adds further information on VME indicator taxa, and aims to build on this work and include carbon sequestration potential on the eastern side of the Burdwood Bank, based on sampling by the RRS James Clark Ross from 100 - 800 m depths in 2018 and 2020.

Data collection

Data collection in the proposed southern MMA on the Burdwood Bank was carried out on the RRS James Clark Ross in collaboration with the British Antarctic Survey (BAS). For logistical reasons, offshore fieldwork was divided across two years. The first part was carried out on the 4th and 5th of December 2018 and the second offshore fieldwork was carried out from the 31st of January to the 3rd February 2020. Data collections included oceanographic conductivity, temperature, and depth (CTD), pelagic zooplankton, and benthic organisms collected with a mini-Agassiz trawl (miniAGT), pictures of the benthic community were collected with a SUCS, high-resolution bathymetry data recorded with a multibeam, sub-bottom profile acquired with a topographic parametric sonar (TOPAS), and cetacean observations. Cruise expedition reports are available (**JR18003** / **JR19002**). The metadata for the 20 datasets acquired during the offshore cruise expeditions have been produced and stored in the SAERI IMS-GIS centre **SAERI metadata portal** and research on all these datasets is ongoing.

This chapter focuses on advancing our understanding of the benthic community using SUCS imagery and (where possible) data from collected specimens.

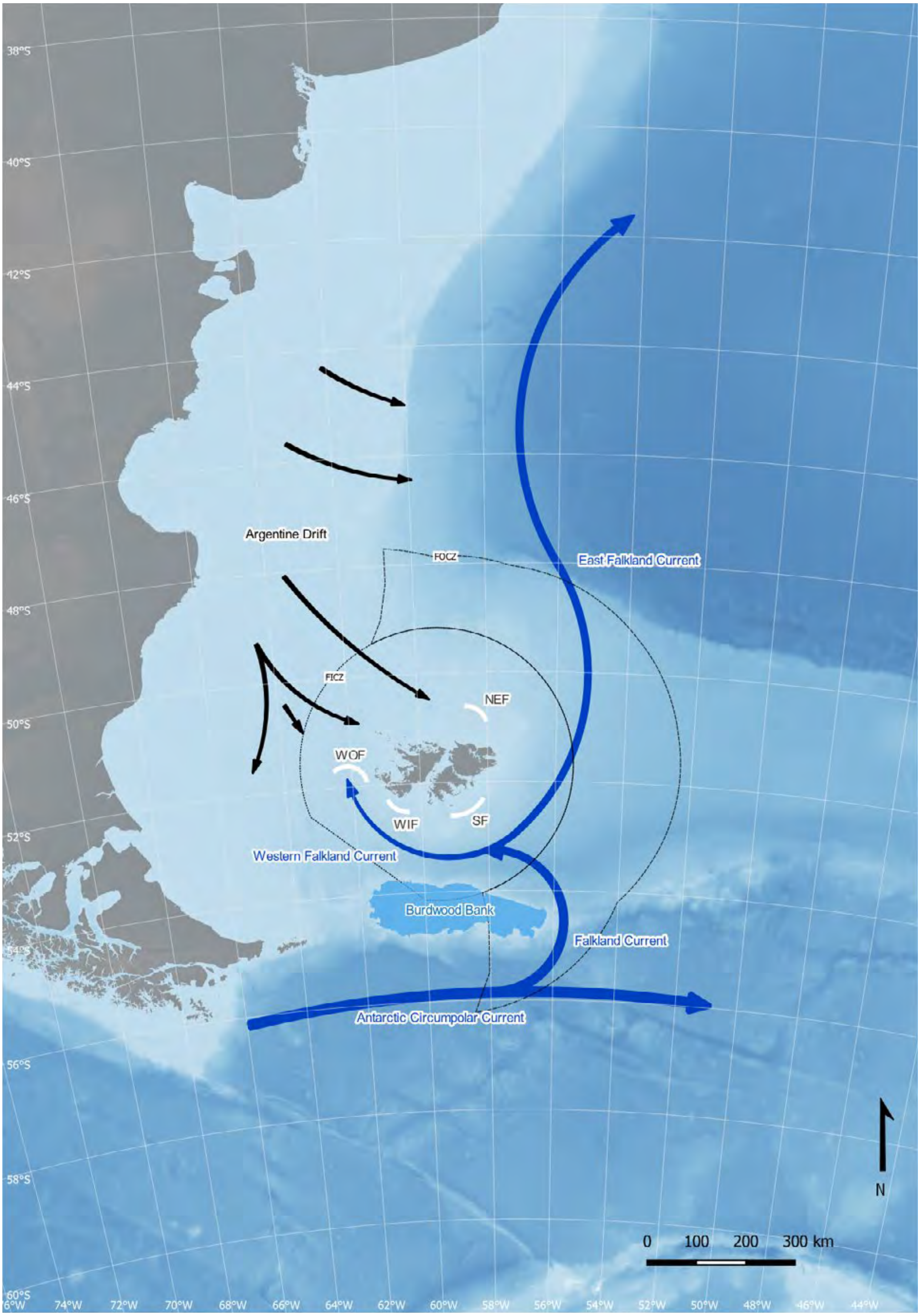


Fig. 2.6: *Simple schematic visualisation of the oceanographic features and frontal systems around the Falkland Islands and Burdwood Bank. WOF = Western Offshore Front; WIF = Western Inshore Front; SF = Southern Front; NEF = North Eastern Front. (Modified from: Arkhipkin et al. 2013).*

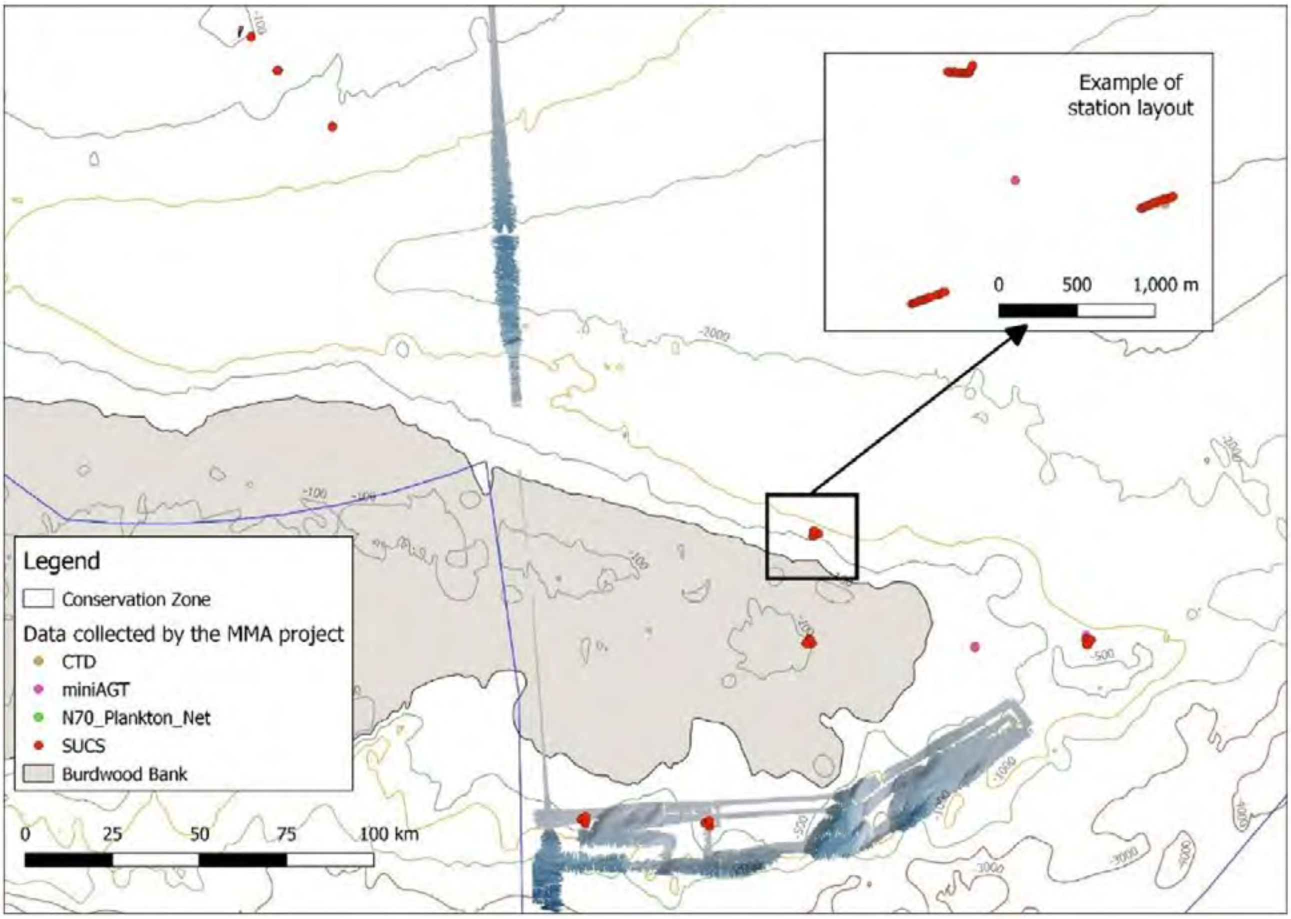


Fig. 2.7. *Map of the Burdwood Bank showing the station and data collection points. Lines represent the depth model, while the patches with different shades of blue represent the multibeam readings. The area of highest carbon storage on the plateau lacks multibeam data entirely, limiting our understanding of long-term sequestration on the Burdwood Bank.*

Seafloor imagery and blue carbon estimation

SUCS was used at five stations on the Burdwood Bank, with the exception of station FIBB4 where weather conditions hampered the camera deployment (Fig. 2.7). For the five stations, three replicates with 20 pictures each were taken (360 images total) (Fig. 2.8). The specimens in each image were identified to the lowest possible taxonomic level, however, due to the difficulty of identifying species from images, most taxa are only identified to phylum or family, unless taxonomic knowledge was available. In some cases, this was possible to species level, e.g., for coral specimens due to taxonomic expertise in the Falkland Islands (N Bax at SAERI for Stylasteridae). However, in terms of an ecosystem wide approach, it was impossible to identify all specimens to species level without further taxonomic collaborations. In order to address this, images were identified to the lowest taxonomic level (which in most cases was to family or phylum), these classifications were delineated into functional groups following the methods of Barnes and Sands (2017) (Table 2.6). Specimen identifications were ascribed using a photo tagging software Photoquad (Trigonis and Sini, 2012).

Functional groups were used to create an identification list for the Burdwood Bank and to determine the density of inorganic and organic carbon content of living and dead biomass based on imagery. Collected specimens were dried and weighed to ascertain the skeletal, tissue and total carbon content of each functional group to clarify their carbon content following the established method of Barnes et al., (2015). This method allows for calculation of the estimated total and yearly carbon on the seabed for each sample site. This approach allowed for an estimate of carbon storage and potential sequestration across slope, shelf and central plateau areas of the Burdwood Bank and comparisons with studies in the South Atlantic and West Antarctic Peninsula. These data provide baseline information and preliminary estimates of carbon sequestration blue carbon for future work.

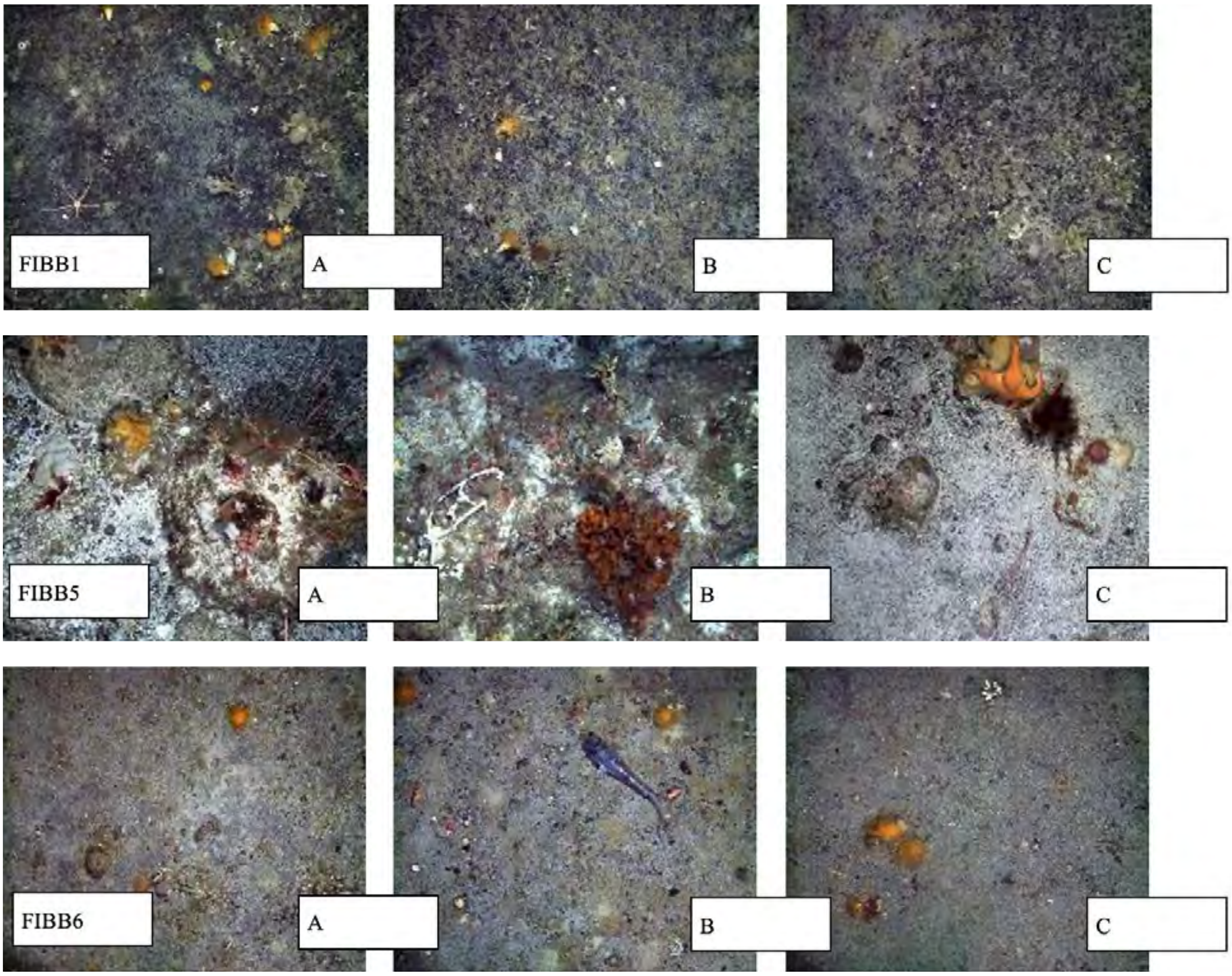


Fig. 2.8. *Example of SUCS images on the Burdwood Bank.*

Table 2.6: functional group classifications used for SUCS images (from Barnes and Sands, 2017).

Sequestration route	**Carbon year^{-1}**
Functional group	**Example taxa**
Pioneer sessile suspension feeders	Encrusting bryozoans, ascidians, some polychaetes
Climax sessile suspension feeders	Demosponges, glass sponges, brachiopods
Sedentary suspension feeders	Basket stars, valviferian isopods, some polychaetes
Mobile suspension feeders	Some brittle stars, crinoids, krill
Epifaunal deposit feeders	Sea cucumbers, some polychaetes
Infaunal soft bodied deposit feeders	Some polychaetes, echiurans, spinculans
Infaunal shelled deposit feeders	Bivalves, irregular sea urchins
Grazers	Regular sea urchins, limpets
Soft bodied, sessile scavenger/predators	Sea pens, soft corals, anemones, hydroids
Hard bodied, sessile scavenger/predators	Cup corals, whip corals, hydrocorals
Soft bodied, mobile scavenger/predators	Some polychaetes, nemerteans, octopus
Hard bodied, mobile scavenger/predators	Sea stars, fish, gastropods, some brittlestars
Joint legged, mobile scavenger/predators	Sea spiders, shrimps, amphipods

Synthesis of results to date:
The British Antarctic Survey (BAS), a partner with the South Atlantic Environmental Research Institute (SAERI), provided ship time in 2018 and 2020 to conduct research into biodiversity on the Burdwood Bank and encountered 1) a large number of cold-water coral species in images and in trawl collections and 2) evidence of large amounts of carbonate material accumulation from imagery, suggesting that the Burdwood Bank could be a geographic 'hot spot' for blue carbon.

New insights into benthic biodiversity on the Burdwood Bank
The percentage of animals collected and preserved at sea and based on complementary imagery from the Burdwood Bank specimen identifications (where possible), were largely represented by the phylum Cnidaria, mainly Scleractinia (cup) and Stylasteridae (lace) corals (combined as cnidaria in Table 2.7), Echinoderms, Porifera (sponges) and Bryozoa were also represented across locations. The abundance and diversity of organisms on the Burdwood Bank was highest at station FIBB5 in particular (on the shallow central plateau), and the analysis of 60 photographs resulted in a final count of 3151 individual identifications, ~30% of which came from FIBB5. However, many invertebrate taxa are colonial, therefore this count only provides a rudimentary overview of seafloor biodiversity, it also fails to account for unobservable infaunal specimens within the sediment (a dominant component of seafloor biodiversity) (Brey and Gerdes, 1999).

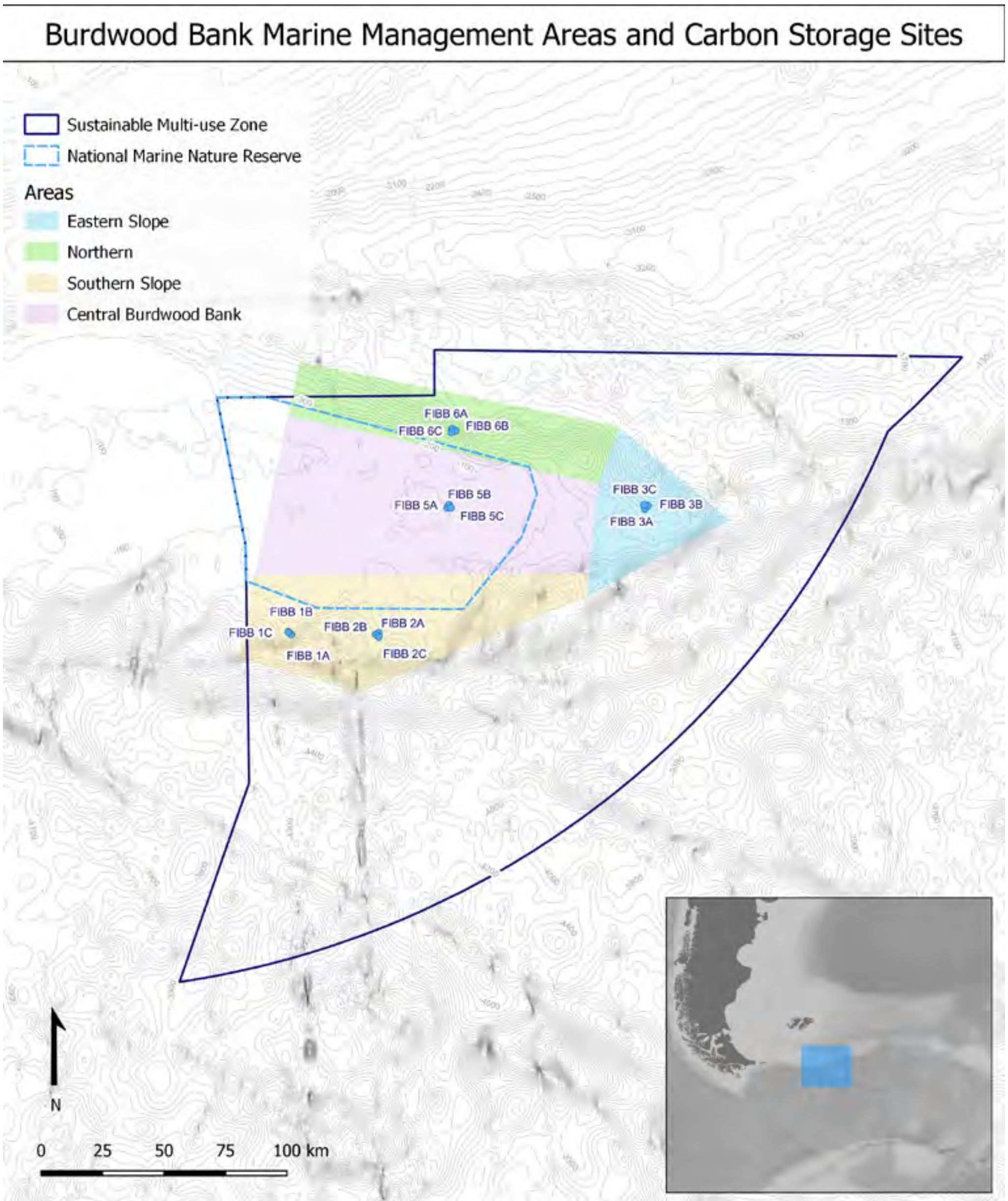
Preliminary insights into Blue Carbon Estimates on the Burdwood Bank
Organic carbon storage capacity was possible for 15 locations across the Eastern, Northern, Southern slope and central plateau region of the Burdwood Bank. Final calculations suggest that 151,969 tonnes of organic carbon is stored across the sampling locations (based on live material only), with station FIBB5 on the plateau in relatively shallow waters (average depth of 124m) accounting for the majority of stored carbon (105,072 tonnes Fig. 2.9). However, the actual sequestration rate appears to be comparatively large when converted to Carbon dioxide equivalents in millions of tonnes of carbon and scaled to inform tonnes of yearly zoobenthic carbon per km^2 (t zC/km^2) (Table 2.8) using the method of Barnes et al. (2020). These preliminary estimates provide justification for future work in this area, especially given the perceived biological richness and presence of important sequesters (such as corals, echinoids, bryozoans) contributing the highest proportion of stored organic carbon based on functional group analysis of SUCS images (Fig. 2.9).

Table 2.7. VME taxa specimen collections were grouped into phylum to provide an overview of diversity sampled at each station on the Burdwood Bank. Bryozoans and cnidarians account for the highest percentage.

Phylum	FIBB1a	FIBB1b	FIBB2a	FIBB2b	FIBB3	FIBB4	FIBB5a	FIBB5b	FIBB6
Annelida	10.1	7.5	8.7	11.2	3.2	7.2	2.1	7.3	6.6
Arthropoda	0.6	1.1	0.8	0.6	0.0	0.0	0.0	0.0	0.0
Brachiopoda	1.9	0.8	2.4	0.8	1.0	3.6	0.0	0.8	0.0
Bryozoa	44.8	6.9	12.2	0.6	11.0	13.9	24.7	30.7	0.0
Chaetognatha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Cnidaria	16.1	15.2	17.7	18.0	23.4	16.1	2.1	0.8	45.3
Crustacea	1.7	5.3	3.5	48.4	9.0	3.6	2.1	8.1	1.3
Echinodermata	18.8	36.0	42.5	11.2	31.9	40.4	30.9	37.1	23.4
Hemichordate	1.0	0.6	2.4	0.0	1.5	1.2	1.0	0.8	0.0
Mollusca	4.8	13.0	2.0	4.6	11.4	4.8	1.0	7.3	4.0
Nematoda	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Porifera	0.2	11.9	7.1	3.0	7.5	8.9	36.1	6.5	17.9

Preliminary insights into Blue Carbon Estimates on the Burdwood Bank

Organic carbon storage capacity was possible for 15 locations across the Eastern, Northern, Southern slope and central plateau region of the Burdwood Bank. Final calculations suggest that 151,969 tonnes of organic carbon is stored across the sampling locations (based on live material only), with station FIBB5 on the plateau in relatively shallow waters (average depth of 124m) accounting for the majority of stored carbon (105,072 tonnes Fig. 2.9). However, the actual sequestration rate appears to be comparatively large when converted to Carbon dioxide equivalents in millions of tonnes of carbon and scaled to inform tonnes of yearly zoobenthic carbon per km^2 (t zC/km^2) (Table 2.8) using the method of Barnes et al. (2020). These preliminary estimates provide justification for future work in this area, especially given the perceived biological richness and presence of important sequesters (such as corals, echinoids, bryozoans) contributing the highest proportion of stored organic carbon based on functional group analysis of SUCS images (Fig. 2.9).



Region	SUCS Camera Sample Sites	Average Depth (m)	Estimated Area (km2)	Carbon Storage Estimates (tonnes)
Northern slope	FIBB6	710	2403.39	11,558
Southern slope	FIBB1/2	400	3925.7	22,849
Central area	FIBB5	124	7959.63	105,072
Eastern area	FIBB3	669	2021	12,489
			Total	151,969 t zC stored*
* +/- >63% error				

Fig. 2.9. *Estimates of stored organic carbon on the Burdwood Bank. SUCS stations encompass the Northern, Southern and Eastern slope and the Central plateau across average depths of 124 - 710 m.*

Table 2.8: Comparative literature for blue carbon. *only including live material estimates.

	Site	zC t km²	Area km²	CO_2 equiv in million tonnes	Data Source
Tropical	Ascension	83	328.5	0.022	Barnes et al. 2019
	associated seamounts	61	282	0.015	Barnes et al. 2019
Temperate	Tristan da Cunha & Gough	201	1253	0.13	Barnes et al. 2021
	associated seamounts	274	7288	0.68	Barnes et al. 2021
Temperate/ Sub-Antarctic	Burdwood bank	*9.3	16310	0.56	Bax et al. Unpublished data in prep
Antarctic	WAP fjords	25	1300	0.12	Zwerschke et al. 2021
	Arctic basin trough	9			Souster et al. 2020

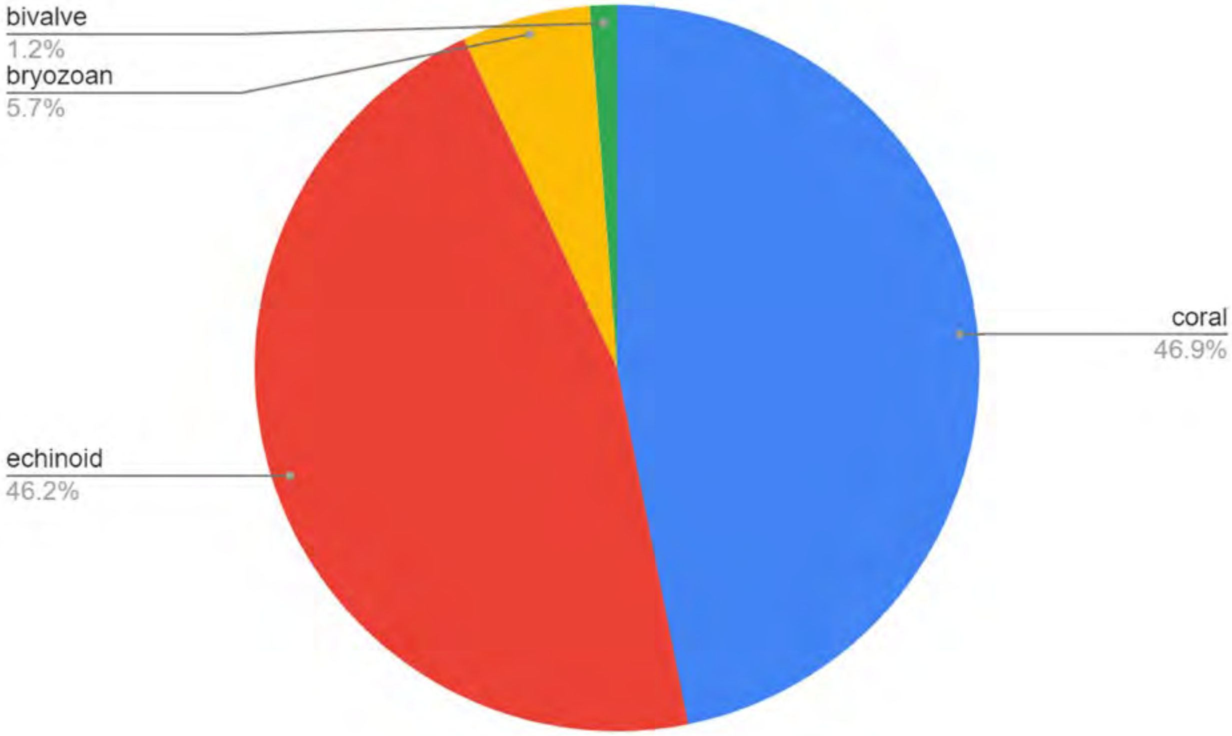


Fig. 2.10. *Pie chart representing the overall contribution of significant carbon-rich taxa from functional groups. Corals and echinoids represent the dominant contribution to carbon storage on the Burdwood Bank based on SUCS image analysis.*

Discussion

Much of the organic carbon stored on the proposed Burdwood Bank MMA could result in long-term sequestration, so long as the seafloor remains undisturbed, and VME habitats persist in the face of other threats (such as climate change). Literature on seafloor blue carbon is scarce, due to the emerging nature of this research, and these Burdwood Bank estimates are the first available for temperate/sub-Antarctic ecosystems to date (Bax et al., in preparation). However, neighbouring blue carbon sites in the South Atlantic and Antarctic do provide some insight (Table 2.8).

The amount of stored carbon appears contextually low in number. For example, the total organic carbon is estimated at 151,969 tonnes (Fig. 2.10). This is equal to removing 29,983 cars off the road for one year **https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator**, a small contribution to the global issue of climate change. However, the potential yearly sequestration rate is comparatively large when converted to Carbon dioxide equivalents in millions of tonnes of carbon and scaled to inform tonnes of zoobenthic carbon per km^2 (t zC/km^2)(Table 2.8) based on living biomass only.

Burdwood Bank estimates in the context of organic carbon stocks across the Falklands Interim Conservation and Management Zone (FICZ) and the Falklands Outer Conservation Zone (FOCZ) extending to 200 nautical miles (~370km), contribute from 12 - 20% of the carbon stock predicted to exist in the upper 10 cm of the sediment column (Bax et al., in review). These estimates of carbon stock are required to gauge the importance of a system in the marine organic carbon cycle (Jennerjahn, 2020). At present there is only minimal and patchy multibeam coverage available for the study sites (Fig. 2.7), and data is especially lacking for shallower depths on the central plateau where biodiversity and carbon storage appear to be highest (Fig. 2.10). Therefore, a more accurate and targeted understanding of the seafloor is needed to validate these findings, particularly at depths above 200m.

Sediment classification mapping would also improve our capacity to estimate benthic carbon stocks more accurately. There are no detailed sediment type classifications available for the Falkland Islands and they are only available by proximity (as modelled in Brewin et al. 2020). For example, Brey and Gerdes, (1999), compared data on the infaunal communities in the adjacent Magellanic region and the Weddell Sea. Their assessment comparing production and carbon biomass based on multibox corer samples show similar sediments between the Magellan region and the Patagonian shelf. Therefore, it is likely that the sediment types across the Magellanic region provide some insight. If this assumption holds, this also suggests that if future work can include dead and infaunal biota in blue carbon estimates, then the amount of stored and potentially sequestered carbon presented herein could be much higher (similar to predictions in Zwerschke et al. 2021 for the West Antarctic fjords). An inability to ground-truth these estimates presently, limits our capacity to compare such studies directly. It also limits our capacity to scale these estimates to the proposed Burdwood Bank MMA boundaries and quantify ecosystem benefits into service and monetary terms (similar to Bayley et al. 2021 for coastal kelp forests).

Marine science voyages of discovery in surrounding locations across the Sub-Antarctic and West Antarctic Peninsula have progressively risen in number and benthic sampling capacity, to include multinational efforts to document the biodiversity of the Burdwood Bank as part of larger working-group goals. These research efforts have coincided with increasing technological advances, for example, deep sea imagery and Remote Operated Vehicle (ROV) capabilities worldwide, and developments in molecular ecology and bioinformatics (e.g., Kaiser et al. 2013, Brasier et al. 2021). However, despite the technology for non-invasive sampling such as with ROVs, the cost of remote science at sea in locations like the Burdwood Bank often limits research time and attention to transit surveys (e.g., on the way to South Georgia or the Antarctic peninsula) (e.g., Expedition ANTARKTIS XIX/5 (LAMPOS) Moyano, 2005; Tatian et al. 2005; Lovrich et al. 2005). With comparatively limited assessments focused directly on the Burdwood Bank (Schejter et al. 2016, 2021). Important insights have been gained, for example into the diversity of species and their relative presence/absence in different habitat types (Doti et al. 2020), enabling multiple taxonomic and biogeographic studies that include specimens from the Burdwood Bank as part of broader phylogenetic assessments (e.g., The Biogeographic Atlas of the Southern Ocean edited by De Broyer, C. and Koubbi, 2014). However, because most seafloor biodiversity data and knowledge reported in the literature comes from opportunistic surveys, it is non-targeted and difficult to quantify.

Modern day seafloor collections also add valuable information to historic legacy collections at the Burdwood Bank, starting with the 1903 'Scotia' Expedition mentioned in Schejter and Mariano, 2021), providing conceivably 119 years of collections to international natural history museums for identification and complementary research, such as paleo-archive analysis to understand past, and future change (Burke and Robinson, 2012). However, the expensive international coordination effort needed to make these collections accessible and discoverable (e.g., as digitally accessible primary biodiversity data Carranza et al. 2022) is currently lacking, as is the taxonomic expertise needed to identify specimens - a time consuming task, in short and diminishing global supply (Saucède et al. 2021). Thus, whilst some VME taxa (e.g., stoney coral groups) are described to family level, other invertebrate groups (e.g., sponges), are quantified based on higher taxonomic groupings (e.g., to class), and in most cases functional groups (e.g., Barnes and Sands, 2017) or as VME indicator taxa grouped by phyla as in this chapter (Table 2.6) and Brewin et al., (2020). These classifications, although informative, reduce the complexity of fine-scale temporal and spatial information, constraining our understanding of biodiversity patterns on the seafloor.

The work of Brewin et al. (2020) modelled and mapped VMEs in the Falkland Islands between 600 and 1800 m for a total of 1570 presence records of indicator taxa across 18 VME indicator taxa groups in the FCZ and ABNJ. Their data, across a broader area than the Burdwood Bank indicates that similarly Cnidarian groups were most common in their dataset, particularly the Scleractinia (23.06%), Gorgonacea (15.41%), Alcyonacea (7.90%), and Stylasteridae (7.39%). Corals provide important ecosystem services such as nutrient cycling and habitat for dependent species. Corals also typify VME indicator status because they are thought to be long-lived, slow growing, late to reproduce and they have fragile calcium carbonate skeletons. These characteristics suggest an inability to recover if populations are removed by destructive fishing practices (Bax and Cairns, 2014, Brewin et al. 2020, Schejter et al. 2016, 2021). Therefore, whilst the Brewin et al. (2020) dataset informs different depths and locations, there is clear evidence from specimen collections herein and sampling by Schejter et al. (2016 and 2021) on the western Burdwood Bank to highlight the conservation significance of cnidarians as both ecosystem engineers and contributing to VMEs. Furthermore, the wealth of VME indicator taxa recorded from across the Falkland Islands over the last decade, including Porifera (Goodwin et al. 2011), Bryozoa and Cnidaria, predominantly belonging to Alcyonacea (including formally classified Gorgonacea), Stylasteridae (Brewin et al. 2020) and Scleractinia (Brewin et al. 2020; Cairns and Polonio, 2013). Scleractinian coral reefs, Sea pen fields, coral gardens (Brewin et al. 2020), Chemosynthetic communities (Nobel, 2014 unpublished data) and field-like aggregations of deep-sea stylasterid (lace) corals across the Falkland Islands plateau (Bax and Cairns, 2014, and Bax unpublished data) including at mesophotic depths (~40m) highlight just how much there is to discover by investing in deep sea science in the Falklands.

Recognising that this is a first-level baseline assessment of blue carbon results and VMEs on the Burdwood Bank, there are ongoing efforts to ground-truth carbon sequestration estimates and to identify specimens to lower taxonomic levels, including the description of new species given the funding and resources to describe them. For example, three specimens of Stylasteridae have been observed as potentially new (Bax unpublished data). There are also ongoing efforts to provide a specific VME indicator taxa guide for the South West Atlantic (Pearman pers. comm), which will greatly improve VME identification and reporting by fisheries observers, if added to existing protocols and resourced effectively. These resources, in combination with SAERI's collaboration with the Falkland Islands Fisheries Department and Consolidated Fisheries Limited to obtain imagery and bycatch data across the Falklands shelf will help to build up broad-scale habitat and VME indicator taxa maps between 200 - 3000 m water depth, in support of fisheries marine stewardship council accreditation of the Toothfish fishery (Brewin et al. 2020, Pearman 2021). The inclusion of a number of habitat and environmental baseline surveys conducted to support offshore exploration of oil and gas (Nobel, 2014, FOGL, 2011) with small –scale high – resolution bathymetry, imagery data and grab sampled fauna and sediment samples, also provide comparative data sets for future analyses across the FCZs. Globally, there are also a number of collaborative working groups forming to progress these data into meaningful ecosystem-wide, multidisciplinary areas of research to inform marine protected area management. For example, the Antarctic Seabed Carbon Capture Change, Sub-Antarctic Blue Carbon and Natural Archives Network are both working across geographies, career stages, nationalities and disciplines to understand the role of the seafloor blue carbon in the carbon cycle, and how ecosystems might respond to future change.

Conclusion

In the near-term, work to understand VME and ecosystem service frameworks that include blue carbon would benefit greatly from an improved understanding of seafloor topography and bottom profiling. There is currently one fishery that operates within the boundaries of the southern proposed MMA, it is Marine Stewardship Council (MSC) certified and it is composed of a single long-line fishing vessel that operates within Falklands waters all along the edge of the continental shelf. Brewin et al. (2020) demonstrated that the impact from this fishery between 600 – 1800 m on VMEs was minimal compared to unregulated fisheries outside the FCZ. Thematic areas of focus for future research should consider VME and ecosystem service frameworks that include blue carbon as potential conservation management tools.

There is a continuous need for quantitative assessments of benthic impacts in managed areas, and an increasing awareness of the different ecological impacts of resource extraction on seafloor environments where management is in place, and where it is not. For example, Brewin et al. (2020) show that there is a lack of data across the entire distribution of VMEs in the FCZ and adjacent Areas Beyond National Jurisdiction (ABNJ). To account for this lack of knowledge, they recommend an interim precautionary management approach. Highlighting the Burdwood Bank as a key location for sustainable fisheries leadership. Whilst also noting some global examples of improved fisheries management (Worm et al. 2009; Halpern et al. 2015; Amoroso et al. 2018), they also caution that unregulated ABNJ fishing could compromise any benefits gained from these initiatives. Benthic biodiversity on the Burdwood Bank will also become increasingly important with ongoing climate change, and species range shifts into and out of polar waters (Melbourne-Thomas et al. 2021). This knowledge, combined with evidence of high benthic biodiversity, movement data for seals and seabirds foraging and transiting through this region regularly (Baylis et al. 2021), and, complementary inshore ecosystem services that include carbon storage (e.g., kelp forests, Bayley et al. 2020) linked to the preliminary evidence of high carbon sequestration potential offshore - all reinforce the significance of the Burdwood Bank as an important conservation focus, with strong justification for MMA designation in 2022.

2.3 OFFSHORE: FISH AND SQUID COMMUNITIES OF BURDWOOD BANK AND THE SOUTHERN PATAGONIAN SHELF – FURTHER INSIGHTS INTO BIOGEOGRAPHY OF THE REGION

SUMMARY:

- The work of many scientists and scientific observers at the Falkland Islands Government Fisheries Department contributed data to understand the ecology of fish and squid on the Burdwood Bank and nearby southern Patagonian Shelf.
- The Burwood Bank, is considered the production engine for the Patagonian Shelf Large Marine Ecosystem (LME), driving patterns of upwelling and biodiversity.
- This study compared and contrasted the fish and squid community structure on the southern Patagonian shelf and slope with those of the Burwood Bank through the standardisation of vessel use and gear type deployed. This method enables a more rigorous analysis of the biogeography of the area.

ABSTRACT:

The Burwood Bank is considered the production engine for the Patagonian Shelf Large Marine Ecosystem (LME) and is central to the high productivity observed in the Atlantic part of the Magellanic Biogeographic Province. The southern Patagonian shelf and slopes host economically important fisheries, such as the Argentinean shortfin squid *Illex argentinus* and Patagonian squid *Doryteuthis gahi* and fish, mainly hakes *Merluccius hubbsi* and hoki (whiptail hake) *Macruronus magellanicus*. A lack of standardisation has hindered progress towards a finer scale understanding of the biogeography of this region. This study uses stardised vessel and gear type in relation to fish and squid abundances, to provide a more rigorous analysis of the biogeography of the area. The aim of this section is to present the results to date that compare and contrast the fish and squid community structure on the southern Patagonian shelf and slope with those of the Burwood Bank.

Pencil urchin,possibly *Notocidaris mortenseni*, from the Burdwood Bank

INTRODUCTION:

A biogeographic Province is a biotic subdivision of biogeographic realms subdivided into ecoregions, which are classified based on their biomes or habitat types. The Patagonian Shelf and Slope, together with the Falkland Islands, comprise the Patagonian Shelf Large Marine Ecosystem (LME), considered part of the Magellanic Biogeographic province - one of the most productive areas in the Southwest Atlantic (see Cousseau et al. 2019). Further south, the sub-Antarctic ecosystem links to the Southern Ocean. These waters are transported onto the shelf by the cold Falkland Current, which diverges from the Antarctic Circumpolar Current (ACC) in the Drake Passage and turns northwards (Peterson & Whitworth, 1989). The temperate ecosystem lies within waters of subtropical origin, transported onto the shelf by the Brazil Current and mixed with temperate shelf waters. At the continental slope south of the Falkland Islands, the Falkland Current splits into a weak branch flowing west around the Islands and a stronger branch flowing east around the Islands (Bianchi et al., 1982). The eastern branch forms the long Falkland Current Front that runs along the Patagonian Shelf break and slope from north of Burdwood Bank to the latitudes of La Plata Estuary (Acha et al., 2004; Franco et al., 2008). It was shown that the Falkland Current Front consists of several meso-scale fronts of intensified productivity (Arkhipkin, et al., 2013). Several productive zones occur in this ecosystem, mainly due to the existence of tidal mixing oceanographic fronts, as well as seasonal fronts originating from cold freshwater inflows into the Strait of Magellan (Belkin et al., 2009). The southern Patagonian shelf and slope ecosystem is therefore complex, especially in relation to oceanographic drivers and their impact on economically important benthic pelagic fish migrations.

In the southern part of the LME, the Burwood Bank hosts a highly productive ecosystem. An important migration destination for a wide variety of seabirds, marine mammals and indeed demersal and pelagic fish. The Burdwood Bank is considered by some to be the 'production engine' for the Patagonian Shelf LME. It forms the beginning of the Scotia Arc and a barrier to the northward flow of the Antarctic Circumpolar Current (ACC). The Bank is 300 km long and 60 km wide. Its 200 m deep summit features smaller bulges, some of which reach to within 50 m of the surface in parts. Piola and Gordon (1989) reported that upon encountering the Burdwood Bank the ACC splits into two branches, which wrap around the bank's edges. Guerrero et al. (1999) highlighted the weak stratification of the waters around the Bank, which is sustained by the advection of a lighter type of intermediate waters. The analyses by Matano et al. (2019) has shown this area to have a highly dynamic hydrography and model simulations show energetic and persistent uplifting of deep waters in this site. These waters are rich in micronutrients and might contribute to the enrichment of the upper layers of the Southern Ocean. Furthermore, the Matano et al. (2019) model analysis indicates that tidal forcing is the main driver for the entrainment of deep waters into the upper layers of the bank and local wind forcing for the detrainment of these waters into the deep ocean. The intricate dynamics of the LME and the Burdwood Bank's unique location sets up a productive community of fish and squid and many nektonic fishes and squid migrate seasonally to frontal zones to feed, moving back to the non-frontal zones for spawning, such as short-fin squid *Illex argentinus*, common hake *Merluccius hubbsi* and hoki *Macruronus magellanicus* (Agnew, 2002). However, despite the understanding of the ichthyofauna and squid fauna across the region, the lack of standardised sampling approaches have hindered a cohesive assessment of their biogeography.

The aim of this section was to compare and contrast the fish and squid community structure on the southern Patagonian shelf and slope with those of the Burwood Bank. This is a synopsis of part of the work that is in preparation for submission to a scientific journal.


Brachiopod, possibly *Liothyrella sp.*, from the Burdwood Bank

METHODS

Sampling

This work was conducted on the *RV Dorada* by various teams at the Falkland Islands Government Fisheries Department using an ENGEL semi-pelagic trawl with 'Super-V' doors was used at all trawl stations. It had a 40.2 m headline and a 38.7 m footrope equipped with rockhoppers. Simrad ITI net monitor sensors had been attached to the upper panel of the trawl. The vertical opening was between 6.9 and 17 m (mean = 11.50 m) and the cod end mesh size was 95 mm, however a cod end liner was also used in order to retain small biological items for scientific study.

Trawling was conducted on 282 stations across the Patagonian Shelf, from the high seas area (shelf and slope) to the north of the Falkland Islands, the Falkland Islands itself (inshore, shelf and slope) and the Burdwood Bank (shelf and slope) (Fig. 2.11). Trawl duration was standardised to 60 mins and Catch Per Unit Effort were calculated for each taxon. The area was split into inshore waters (<120 m – Falkland Islands (FI) only), shelf waters (>=120 < 300 m; High Sea (HS), FI and Burdwood Bank (BB) and finally slope waters (>=300 <1500 m, HS, FI, BB). The work was conducted by the Falkland Islands Government Fisheries Department between 2002 and 2007. Species were identified to the lowest taxonomic level using established guides and experts.

The catches at all stations were weighed using an electronic marine adjusted balance (POLS, min 10 g, and max 80 kg). Finfish and rajids were measured (LT, LPA and WD) to the nearest centimetre below and the sex and stage of maturity were recorded for all specimens sampled. Individual weights were recorded to the nearest gram using a POLS balance or, for larger specimens, to the nearest 20 grams using the Scanvaegt balances. Cephalopods were analysed for length, sex, maturity and weight, with statoliths extracted from sub samples.

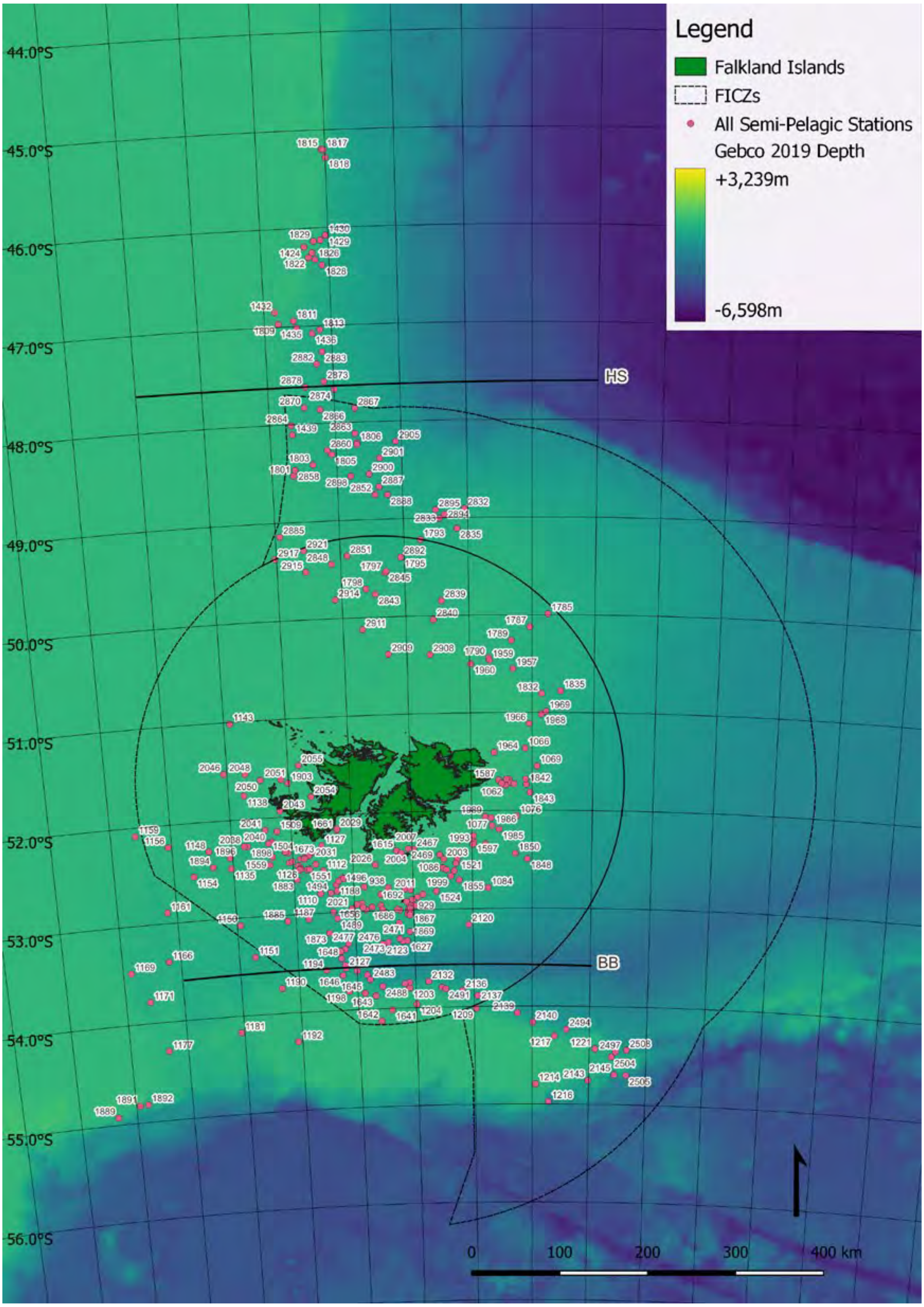


Fig. 1.11. *Mapped location of 282 semi-pelagic stations across the Patagonian Shelf, from the high seas area (shelf and slope) to the north of the Falkland Islands, the Falkland Islands itself (inshore, shelf and slope) and the Burdwood Bank (shelf and slope).*

Data Analyses

Species accumulation curves using Chao-2 and observed number of species (Sobs) estimators, with standard deviation, were produced in order to assess sampling effort based on faunal species occurrence data collected (Chao et al. 2009). A log (n+1) transformation was used on CPUEs of taxa encountered by station to down weigh the influence of highly abundant taxa. A three factor (depth, month and year) permutated analysis of variance (PERMANOVA) was carried out, using the Bray–Curtis dissimilarity measure, on species abundance data to establish to which extent depth and seasonal changes impact the structure of the community (Anderson et al. 2008). P values were obtained after 999 permutations. Non Metric Multidimensional Scaling (nMDS) was used for data exploration (not presented) using a Bray–Curtis resemblance matrix. Then Canonical Analysis of Principal coordinates (CAP) was also performed, using a Bray–Curtis resemblance matrix, to further visualise any community differences, with the most abundant taxa overlaid onto the plots as vectors to determine which depth or season were most influential for particular taxa.

RESULTS:

General Observations

A total of 169 taxa were recorded during these surveys (Table 2.9) comprising 114 fish, 3 hagfish, 9 octopus, 4 shark 13 skate and 26 squid taxa. Table 2.10 shows the 50 ranked abundant species on the BB with FI and HS species for reference.

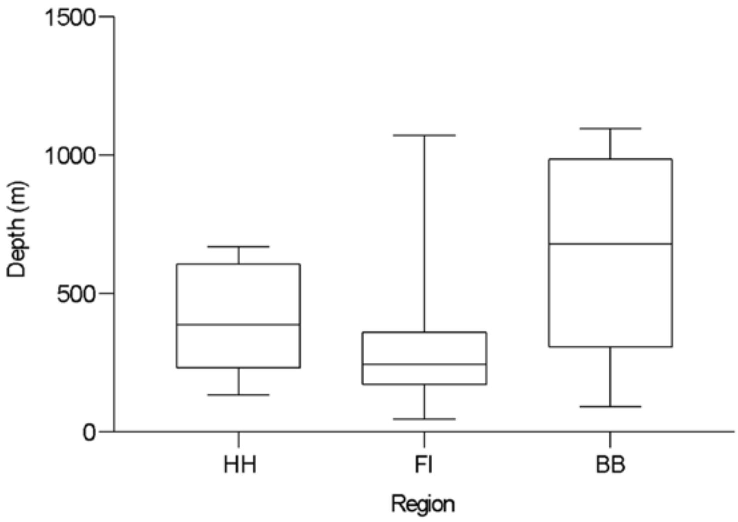


Fig. 2.12. *Depth ranges sampled between regions. Boxes represent 25th, median and 75th percentiles; whiskers represent minimum and maximum*

Table 2.9: Species encountered in the survey ranked by abundance

Group	ScientificName accepted	Order	Family	CPUE (kg/hr)
Fish	*Micromesistius australis*	Gadiformes	Gadidae	41898.4368
Fish	*Macruronus magellanicus*	Gadiformes	Merlucciidae	26765.9248
Fish	*Macrourus carinatus*	Gadiformes	Macrouridae	8395.2158
Squid	*Doryteuthis (Amerigo) gahi*	Myopsida	Loliginidae	4057.0749
Squid	*Illex argentinus*	Oegopsida	Ommastrephidae	1757.1417
Fish	*Patagonotothen ramsayi*	Perciformes	Nototheniidae	999.1325
Fish	*Merluccius hubbsi*	Gadiformes	Merlucciidae	604.1765

Group	ScientificName accepted	Order	Family	CPUE (kg/hr)
Fish	*Sprattus fuegensis*	Clupeiformes	Clupeidae	493.8893
Squid	*Moroteuthopsis ingens*	Oegopsida	Onychoteuthidae	477.8455
Fish	*Coelorinchus fasciatus*	Gadiformes	Macrouridae	386.4336
Fish	*Dissostichus eleginoides*	Perciformes	Nototheniidae	346.4537
Fish	*Antimora rostrata*	Gadiformes	Moridae	313.0462
Fish	*Gymnoscopelus nicholsi*	Myctophiformes	Myctophidae	249.8987
Fish	*Merluccius australis*	Gadiformes	Merlucciidae	199.3318
Skate	*Bathyraja griseocauda*	Rajiformes	Arhynchobatidae	184.9337
Fish	*Salilota australis*	Gadiformes	Moridae	166.1131
Fish	*Genypterus blacodes*	Ophidiiformes	Ophidiidae	153.1797
Shark	*Lamna nasus*	Lamniformes	Lamnidae	138.9332
Shark	*Schroederichthys bivius*	Carcharhiniformes	Scyliorhinidae	118.1755
Fish	*Stromateus brasiliensis*	Perciformes	Stromateidae	109.3841
Skate	*Bathyraja brachyurops*	Rajiformes	Arhynchobatidae	103.6710
Skate	*Bathyraja cousseauae*	Rajiformes	Arhynchobatidae	98.7737
Skate	*Bathyraja albomaculata*	Rajiformes	Arhynchobatidae	81.5493
Fish	*Cottoperca gobio*	Perciformes	Bovichtidae	74.5289
Fish	*Lampris immaculatus*	Lampriformes	Lampridae	55.8058
Skate	*Dipturus chilensis*	Rajiformes	Rajidae	53.6920
Fish	*Nototheniidae*	Perciformes	Nototheniidae	51.9205
Fish	*Squalus acanthias*	Squaliformes	Squalidae	50.4823
Skate	*Bathyraja magellanica*	Rajiformes	Arhynchobatidae	32.7114
Fish	*Notophycis marginata*	Gadiformes	Moridae	32.3693
Fish	*Macrourus holotrachys*	Gadiformes	Macrouridae	31.5042
Fish	*Champsocephalus esox*	Perciformes	Channichthyidae	30.6089
FIsh	*Icichthys australis*	Scombriformes	Centrolophidae	27.1455
Fish	*Myctophidae sp*	Myctophiformes	Myctophidae	25.9397
Skate	*Bathyraja scaphiops*	Rajiformes	Arhynchobatidae	25.3023
Fish	*Echiodon cryomargarites*	Ophidiiformes	Carapidae	23.9793
Skate	*Amblyraja doellojuradoi*	Rajiformes	Rajidae	23.8049
Fish	*Gymnoscopelus bolini*	Myctophiformes	Myctophidae	22.5889
Fish	*Cottunculus granulosus*	Perciformes	Psychrolutidae	20.3135

Group	ScientificName accepted	Order	Family	CPUE (kg/hr)
Skate	*Bathyraja multispinis*	Rajiformes	Arhynchobatidae	19.6057
Fish	*Patagonotothen tessellata*	Perciformes	Nototheniidae	17.7535
FIsh	*Iluocoetes fimbriatus*	Perciformes	Zoarcidae	17.5720
Fish	*Halargyreus johnsonii*	Gadiformes	Moridae	17.2475
Fish	*Bassanago albescens*	Anguilliformes	Congridae	16.3593
Fish	*Seriolella porosa*	Scombriformes	Centrolophidae	15.6993
Octopus	*Enteroctopus megalocyathus*	Octopoda	Enteroctopodidae	15.4006
Fish	*Allothunnus fallai*	Scombriformes	Scombridae	15.1307
Fish	*Gymnoscopelus sp*	Myctophiformes	Myctophidae	13.9180
Fish	*Notacanthus chemnitzii*	Notacanthiformes	Notacanthidae	13.7232
FIsh	*Eleginops maclovinus*	Perciformes	Eleginopsidae	13.5390
Skate	*Psammobatis sp*	Rajiformes	Arhynchobatidae	12.0166
Skate	*Bathyraja macloviana*	Rajiformes	Arhynchobatidae	11.6298
Fish	*Alepocephalus productus*	Alepocephaliformes	Alepocephalidae	11.4952
Fish	*Protomyctophum choriodon*	Myctophiformes	Myctophidae	10.9141
Octopus	*Muusoctopus longibrachus akambei*	Octopoda	Enteroctopodidae	9.0744
Fish	*Neoachiropsetta milfordi*	Pleuronectiformes	Achiropsettidae	8.5876
Fish	*Coryphaenoides subserrulatus*	Gadiformes	Macrouridae	6.7727
Squid	*Martialia hyadesi*	Oegopsida	Ommastrephidae	6.6924
Fish	*Sebastes oculatus*	Perciformes	Sebastidae	5.9280
Fish	*Ceratias tentaculatus*	Lophiiformes	Ceratiidae	5.6807
Skate	*Bathyraja papilionifera*	Rajiformes	Arhynchobatidae	4.8206
Fish	*Psychrolutes marmoratus*	Perciformes	Perciformes	4.7386
Fish	*Patagonotothen wiltoni*	Perciformes	Nototheniidae	3.9987
Fish	*Patagonotothen guntheri*	Perciformes	Nototheniidae	3.6866
Fish	*Magnisudis prionosa*	Aulopiformes	Paralepididae	3.1798
Fish	*Gymnoscopelus braueri*	Myctophiformes	Myctophidae	3.0075
Fish	*Paradiplospinus gracilis*	Scombriformes	Gempylidae	2.9815
Fish	*Lepidion ensiferus*	Gadiformes	Moridae	2.8025

Group	ScientificName accepted	Order	Family	CPUE (kg/hr)
Fish	*Lampanyctus achirus*	Myctophiformes	Myctophidae	2.6865
Fish	*Bathylagus antarcticus*	Argentiniformes	Bathylagidae	2.4391
Fish	*Mancopsetta maculata*	Pleuronectiformes	Achiropsettidae	2.3648
Fish	*Trigonolampa miriceps*	Stomiiformes	Stomiidae	2.3590
Fish	*Pseudocyttus maculatus*	Zeiformes	Oreosomatidae	2.2391
Fish	*Muraenolepis orangiensis*	Gadiformes	Muraenolepididae	2.2384
Fish	*Lampanyctus macdonaldi*	Myctophiformes	Myctophidae	2.0256
Fish	*Mancopsetta sp*	Pleuronectiformes	Achiropsettidae	1.9951
Skate	*Bathyraja meridionalis*	Rajiformes	Arhynchobatidae	1.9901
Fish	*Coelorinchus kaiyomaru*	Gadiformes	Macrouridae	1.6893
Fish	*Symbolophorus boops*	Myctophiformes	Myctophidae	1.6623
Squid	*Bathyteuthis abyssicola*	Bathyteuthida	Bathyteuthidae	1.6565
Octopus	*Graneledone yamana*	Octopoda	Megaleledonidae	1.5714
Fish	*Patagonotothen longipes*	Perciformes	Nototheniidae	1.3876
Fish	*Protomyctophum*	Myctophiformes	Myctophidae	1.1730
Squid	*Histioteuthis eltaninae*	Oegopsida	Histioteuthidae	1.1115
Fish	*Lepidonotothen squamifrons*	Perciformes	Nototheniidae	0.9421
Octopus	*Muusoctopus eureka*	Octopoda	Enteroctopodidae	0.9261
Hagfish	*Myxine fernholmi*	Myxiniformes	Myxinidae	0.8299
Skate	*Psammobatis normani*	Rajiformes	Arhynchobatidae	0.7854
Fish	*Agrostichthys parkeri*	Lampriformes	Regalecidae	0.7486
Octopus	*Opisthoteuthis hardyi*	Octopoda	Opisthoteuthidae	0.6235
Fish	*Seriolella caerulea*	Scombriformes	Centrolophidae	0.6166
Octopus	Eledonidae sp	Octopoda	Octopodidae	0.5761
Squid	*Gonatus antarcticus*	Oegopsida	Gonatidae	0.5641
Fish	*Bathylagus tenuis*	Argentiniformes	Bathylagidae	0.5473
Fish	*Achiropsetta tricholepis*	Pleuronectiformes	Achiropsettidae	0.5449
Fish	*Anotopterus pharao*	Aulopiformes	Anotopteridae	0.5395
Fish	*Gymnoscopelus hintonoides*	Myctophiformes	Myctophidae	0.5377
Squid	*Filippovia knipovitchi*	Oegopsida	Onychoteuthidae	0.4440
Fish	*Electrona subaspera*	Myctophiformes	Myctophidae	0.4043

Group	ScientificName accepted	Order	Family	CPUE (kg/hr)
Fish	*Borostomias antarcticus*	Stomiiformes	Stomiidae	0.4024
Fish	*Chauliodus sloani*	Stomiiformes	Stomiidae	0.3950
Fish	*Bathylagus gracilis*	Argentiniformes	Bathylagidae	0.3771
Fish	*Guttigadus globosus*	Gadiformes	Moridae	0.3545
Fish	*Melanonidae sp.*	Gadiformes	Melanonidae	0.3272
Hagfish	*Myxine australis*	Myxiniformes	Myxinidae	0.2927
Fish	*Cataetyx messieri*	Ophidiiformes	Bythitidae	0.2838
Squid	*Batoteuthis skolops*	Oegopsida	Batoteuthidae	0.2703
Squid	*Brachioteuthis sp*	Oegopsida	Brachioteuthidae	0.2682
Squid	Cephalopoda sp			0.2284
Fish	Liparidae sp	Perciformes	Liparidae	0.2246
Fish	*Paranotothenia magellanica*	Perciformes	Nototheniidae	0.2218
Squid	*Slosarczykovia circumantarctica*	Oegopsida	Brachioteuthidae	0.2215
Fish	*Epigonus robustus*	Acropomatiformes	Epigonidae	0.1829
Fish	*Bathylagus sp*	Argentiniformes	Bathylagidae	0.1800
Shark	*Etmopterus lucifer*	Squaliformes	Etmopteridae	0.1791
Fish	*Stomias gracilis*	Stomiiformes	Stomiidae	0.1533
Fish	*Arctozenus risso*	Aulopiformes	Paralepididae	0.1478
Octopus	Octopodidae sp	Octopoda	Octopodidae	0.1394
Octopus	*Bathypolypus sp*	Octopoda	Bathypolypodidae	0.1391
Octopus	*Opisthoteuthis sp*	Octopoda	Opisthoteuthidae	0.1375
Squid	*Semirossia patagonica*	Sepiida	Sepiolidae	0.1222
Squid	*Chiroteuthis veranii*	Oegopsida	Chiroteuthidae	0.1132
Fish	*Macrourus sp*	Gadiformes	Macrouridae	0.1126
Fish	*Careproctus sp*	Perciformes	Liparidae	0.1035
Fish	*Scopelosaurus hamiltoni*	Aulopiformes	Notosudidae	0.0997
Fish	Chiasmodontidae	Scombriformes	Chiasmodontidae	0.0922
Fish	*Mancopsetta sp*	Pleuronectiformes	Achiropsettidae	0.0900
Squid	*Neorossia caroli*	Sepiida	Sepiolidae	0.0826
Fish	*Stomias boa*	Stomiiformes	Stomiidae	0.0711
Hagfish	*Myxine sp*	Myxiniformes	Myxinidae	0.0708

Group	ScientificName accepted	Order	Family	CPUE (kg/hr)
Squid	*Mastigoteuthis psychrophila*	Oegopsida	Mastigoteuthidae	0.0705
Fish	*Electrona carlsbergi*	Myctophiformes	Myctophidae	0.0667
Squid	*Taonius sp*	Oegopsida	Cranchiidae	0.0654
Fish	Stomiidae	Stomiiformes	Stomiidae	0.0621
Fish	*Poromitra crassiceps*	Beryciformes	Melamphaidae	0.0578
FIsh	*Guttigadus kongi*	Gadiformes	Moridae	0.0559
Squid	*Brachioteuthis linkovskyi*	Oegopsida	Brachioteuthidae	0.0495
Squid	*Moroteuthopsis longimana*	Oegopsida	Onychoteuthidae	0.0451
Fish	*Avocettina infans*	Anguilliformes	Nemichthyidae	0.0451
Fish	*Paraliparis sp*	Perciformes	Liparidae	0.0442
Fish	*Protomyctophum gemmatum*	Myctophiformes	Myctophidae	0.0428
Squid	*Histioteuthis sp*	Oegopsida	Histioteuthidae	0.0373
Squid	*Galiteuthis glacialis*	Oegopsida	Cranchiidae	0.0357
Squid	*Psychroteuthis glacialis*	Oegopsida	Psychroteuthidae	0.0328
Fish	*Lampadena notialis*	Myctophiformes	Myctophidae	0.0298
Squid	*Psychroteuthis sp*	Oegopsida	Psychroteuthidae	0.0294
Fish	*Guttigadus globosus*	Gadiformes	Moridae	0.0213
Fish	*Stomias sp*	Stomiiformes	Stomiidae	0.0194
Fish	*Rosenblattia robusta*	Acropomatiformes	Epigonidae	0.0183
Fish	*Chiasmodon niger*	Scombriformes	Chiasmodontidae	0.0155
Fish	*Lycenchelys bachmanni*	Perciformes	Zoarcidae	0.0147
Fish	*Melanonus gracilis*	Gadiformes	Melanonidae	0.0147
Squid	*Mastigoteuthis sp*	Oegopsida	Mastigoteuthidae	0.0128
Fish	*Diaphus hudsoni*	Myctophiformes	Myctophidae	0.0115
Fish	*Bathydraco joannae*	Perciformes	Bathydraconidae	0.0111
Fish	*Agonopsis chiloensis*	Perciformes	Agonidae	0.0106
Fish	*Diplophos sp*	Stomiiformes	Gonostomatidae	0.0094
Fish	*Electrona sp*	Myctophiformes	Myctophidae	0.0089
Squid	Cranchiidae	Oegopsida	Cranchiidae	0.0088
Fish	Neoscopelidae	Myctophiformes	Neoscopelidae	0.0077

Group	ScientificName accepted	Order	Family	CPUE (kg/hr)
Fish	*Gymnoscopelus fraseri*	Myctophiformes	Myctophidae	0.0076
Fish	Stomiidae	Stomiiformes	Malacosteidae	0.0059
Fish	*Maurolicus muelleri*	Stomiiformes	Sternoptychidae	0.0055
Fish	*Metelectrona ventralis*	Myctophiformes	Myctophidae	0.0047
Fish	*Lampanyctus sp*	Myctophiformes	Myctophidae	0.0041
Fish	Zoarcidae sp	Perciformes	Zoarcidae	0.0015
Fish	*Cynomacrurus piriei*	Gadiformes	Macrouridae	0.0012
Fish	*Protomyctophum bolini*	Myctophiformes	Myctophidae	0.0008

Unidentified crustacean, possibly *Eurypodius longirostris*, from the Burdwood Bank

Table 2.10: 50 ranked abundant species on the BB with FI and HS species for reference.

Species	BB	FI	HS
Macrourus carinatus	6462.286	1422.799	510.1308
Macruronus magellanicus	681.4028	24536.27	1548.247
Micromesistius australis	570.4517	41293.55	34.43176
Sprattus fuegensis	477.1799	16.70933	0
Antimora rostrata	304.2949	8.751365	0
Dissostichus eleginoides	210.3143	129.3001	6.839242
Patagonotothen ramsayi	180.0286	785.7779	33.32604
Moroteuthis ingens	95.75949	0	0
Bathyraja griseocauda	77.36969	101.3109	6.253086
Schroederichthys bivius	75.15419	43.02134	0
Gymnoscopelus nicholsi	69.72473	168.2366	11.93731
Coelorhynchus fasciatus	58.93233	0	0
Bathyraja brachyurops	42.83797	52.46235	8.370716
Bathyraja cousseauae	39.78855	57.36386	1.621329
Macrourus holotrachys	27.28181	4.222397	0
Icichthys australis	26.43614	0.60717	0.102222
Myctophidae ap	25.31211	0.596044	0.031579
Echiodon cryomargarites	23.9733	0.006043	0
Lampris immaculatus	19.068	36.73777	0
Halargyreus johnsonii	16.81515	0.432353	0
Merluccius australis	16.5271	182.8047	0
Seriolella porosa	14.84873	0.850602	0
Notacanthus chemnitzi	13.65589	0.067338	0
Salilota australis	11.61438	154.4987	0
Alepocephalus productus	11.49517	0	0
Doryteuthis (Amerigo) gahi	8.625927	3831.062	217.3868
Cottoperca gobio	8.276626	66.25227	0
Squalus acanthias	7.216417	42.95034	0.31551
Amblyraja doellojuradoi	6.893292	14.26033	2.651267
Coryphaenoides subserrulatus	6.772724	0	0
Physiculus marginatus	5.592037	0	0

Species	BB	FI	HS
Ceratias tentaculatus	5.590024	0.090647	0
Allothunnus fallai	4.967742	10.16299	0
Bathyraja papilionifera	4.820567	0	0
Bathyraja albomaculata	4.613146	70.8389	6.097214
Gymnoscopelus bolini	4.218896	14.6404	3.729573
Magnisudis prionosa	2.920686	0.038915	0.220228
Bathyraja scaphiops	2.909268	22.39299	0
Iluocoetes fimbriatus	2.705414	6.02183	8.844712
Lepidion ensiferus	2.674791	0.127667	0
Paradiplospinus gracilis	2.671231	0.283203	0.027049
Gymnoscopelus sp	2.488401	9.216586	2.213016
Bathyraja multispinis	2.442545	17.16311	0
Gymnoscopelus braueri	2.429555	0.577963	0
Mancopsetta milfordi	2.372393	0	0
Bathylagus antarcticus	2.302403	0.136667	0
Trigonolampa miriceps	2.271372	0.087626	0
Pseudocyttus maculatus	2.239126	0	0
Psychrolutes marmoratus	2.198446	2.54014	0
Patagonotothen guntheri	2.066667	1.619939	0

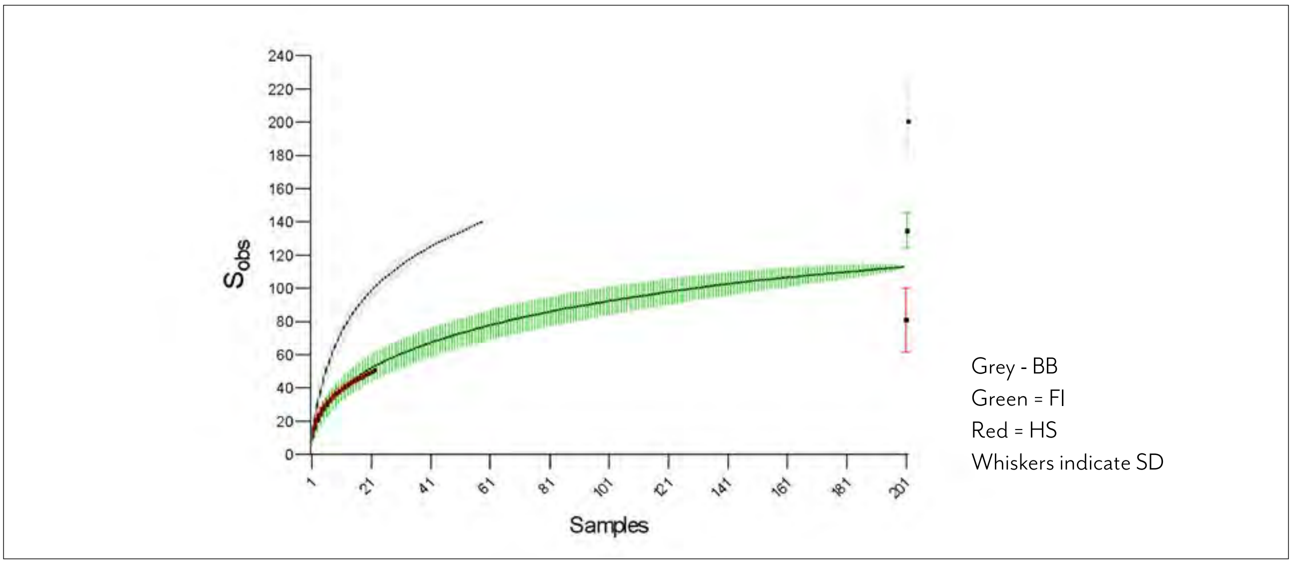


Fig. 2.13. *The species accumulation curve for the sampling effort over the surveys and the Chao2 estimate for each region, demonstrating that a number of species remain to be included in the full species inventory. What is very clear is that the species richness curve for the Burdwood Bank is very steep with a Chao2 estimate of 200.5 ± 24.9 indicating a much greater species diversity on the Burdwood Bank compared to the High Seas area and in the Falkland Island Conservation Zone.*

Multivariate analyses

Results from PERMANOVA demonstrated that depth influenced community structure but not month and year (Table 2.11). Region was not included as exploratory analyses showed that there were differences in community structure by region.

The separation of community structure becomes clearer when these are re analysed and compared between the depth strata (shelf and slope).

Table 2.11. PERMANOVA results on communities for the whole data set

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
De	1	29754	29754	4.3657	0.004	999
Ye	4	19144	4786.1	0.80673	0.774	996
Mo	4	16631	4157.7	0.71672	0.856	999
DexYe**	6	24442	4073.7	0.62283	0.8	998
DexMo**	5	23223	4644.7	0.77248	0.661	999
YexMo**	1	6892.8	6892.8	1.4417	0.266	980
DexYexMo**	2	10207	5103.6	2.32	0.002	999
Res	253	5.57E+05	2199.9			

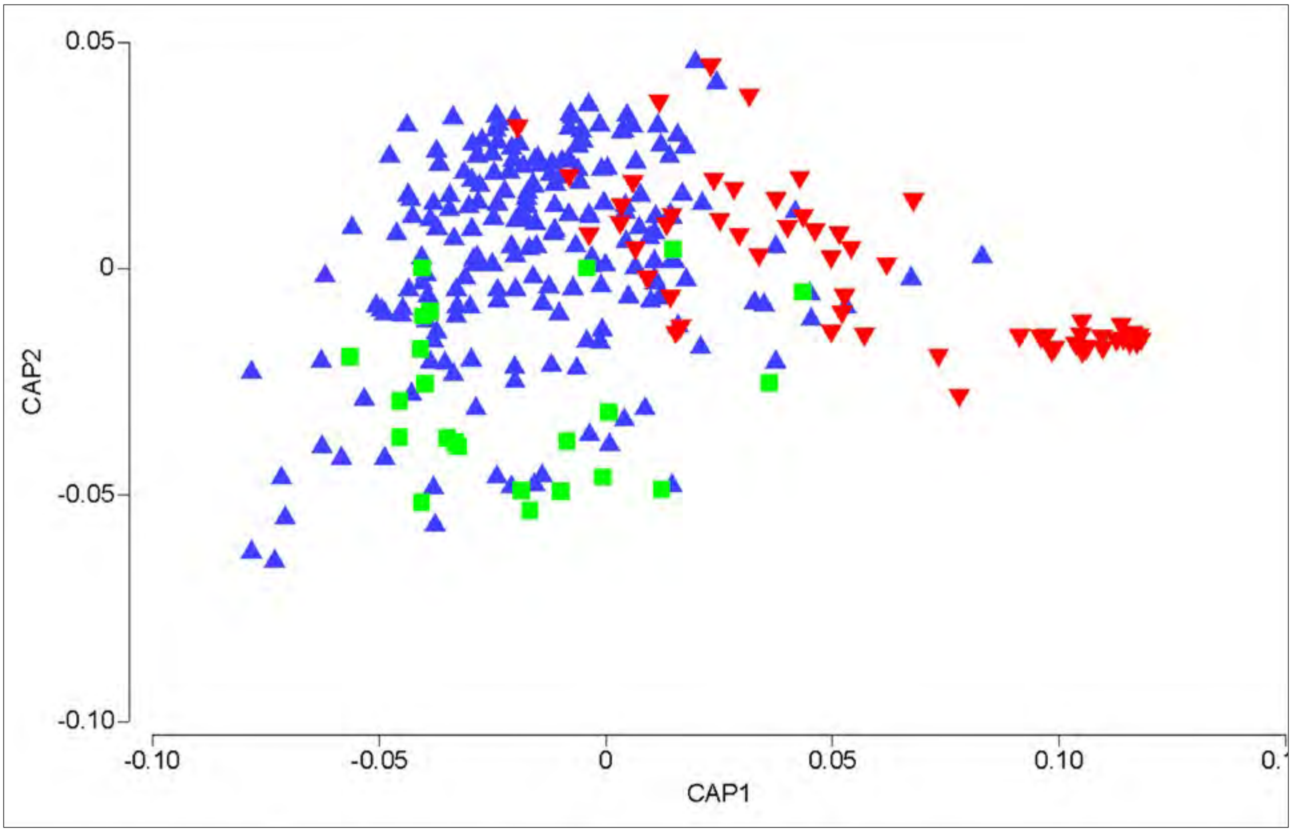


Fig. 2.14. *Illustrates the differences in community structure between the three regions. There is a general separation for each of the regions. Each point represents a trawl. Blue – FI; Red = BB; Green = HS*

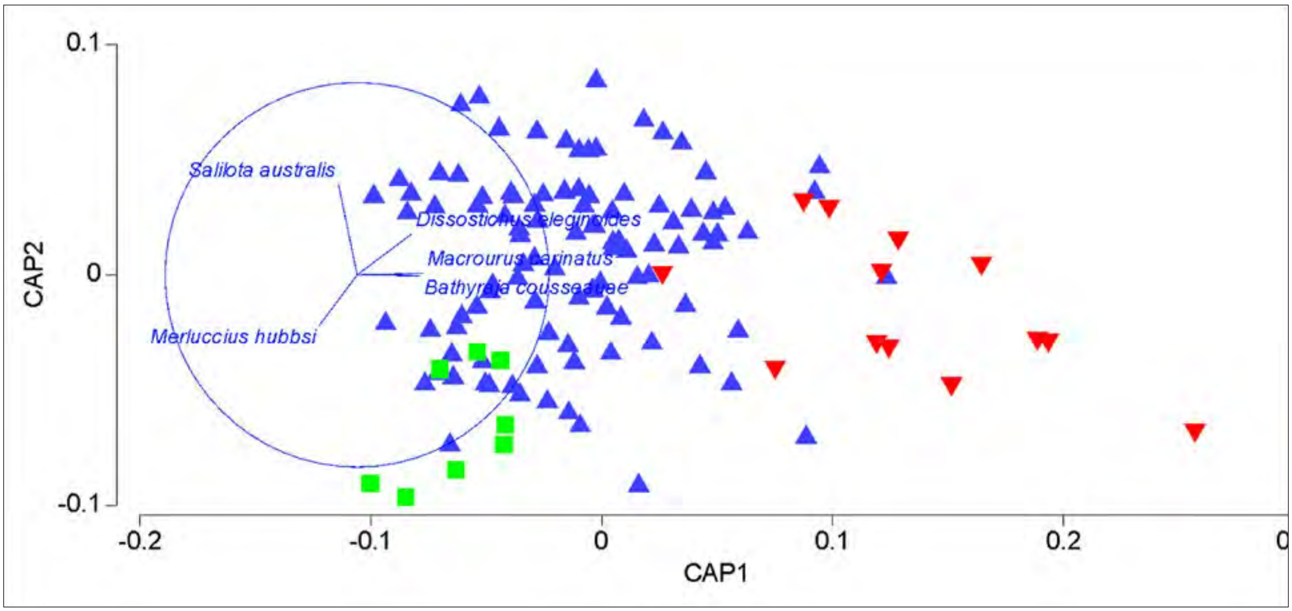


Fig. 2.15. *Illustrates the community structure of the shelf ecosystems of each environment. Each point represents a trawl. Blue – FI; Red = BB; Green = HS. The vectors illustrate which common species influence the community structure. The CAP analyses results in a correct classification of 73.786%, 76.923% and 75% for FI, BB and HS respectively.*

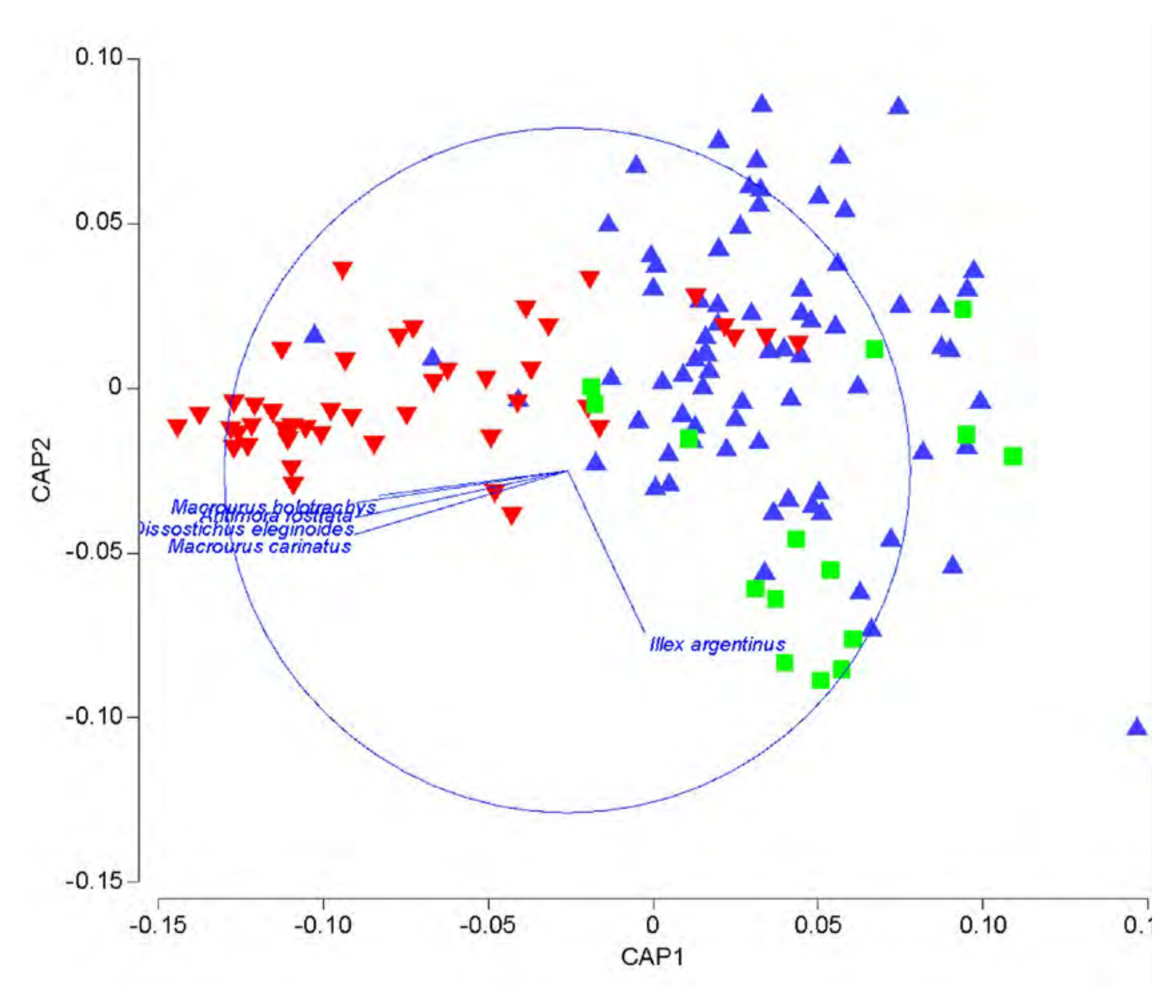


Fig. 2.16. *Illustrates the community structure of the slope ecosystems of each environment. Each point represents a trawl. Blue – FI; Red = BB; Green = HS. The vectors illustrate which common species influence the community structure. The CAP analyses results in in a correct classification of 72%, 79.545% and 53.333 for FI, BB and HS respectively*

Discussion

The southern Patagonian Shelf is considered to be a part of the Magellanic Biogeographic province (see Cousseau et al. 2019). However, the Burdwood, as a component of the province, is comparatively unexplored, with limited sampling focused directly in offshore environments (Brewin et al. 2020). And although the Falkland Islands and the Burwood Bank have had continued fishing pressure for many decades and indeed a number of systematic research cruises, research has often been non-targeted. The exception being the 2018 and 2020 SAERI and the British Antarctic Survey (BAS) collaborative cruise to characterise the Burdwood Bank as part of the MMA project focused on the seafloor (see section 2.2). Outside of this survey, sampling efforts have often represented components of larger sampling regimes (e.g., The Biogeographic Atlas of the Southern Ocean edited by De Broyer, C. and Koubbi, 2014) so that data reported in the literature represent only a few stations of a broader-scale survey, which has hindered the quantification of community dynamics, including fish and squid despite their importance to these ecosystems. Consequently, this is the first study to cover the geographic area of the eastern to southeastern part of the Patagonian Shelf in detail, and to such an extent using standard sampling techniques. The standardisation here is the vessel used and gear deployed which enables a more rigorous analysis of the biogeography of the area than past studies.

The synopsis presented herein illustrates the high biological diversity on the Burwood Bank compared to other parts of the Falkland Islands and High Seas area to the north of the FCZs with regards to fish and squid. This pattern is also reflected in the benthic communities (see section 2.1 and section 2.2 herein), however, without a similar standardisation and quantitative analysis e.g., species level classifications and multiple years of data this pattern is only superficially matched based on seafloor imagery. Furthermore, this work illustrates the different community structure on the shelves and slopes of the areas with the Burdwood Bank showing greater dissimilarity than the other regions. Some of the reasons for this include the habitat complexity of the seamount / ridge systems and the unique geomorphology, bathymetry and indeed hydrodynamic complexity. And, importantly, also the Burdwood Bank's proximity to the ACC. Based on the initial results presented here, we confirm that the Burdwood Bank represents a meeting of sub-Antarctic and Magellanic fauna. This is the subject of ongoing work that is being prepared for publication in a scientific journal to illustrate how unique the Burdwood Bank's marine ecosystems are.

Conclusion

Recognition of the Burdwood Bank as globally unique is building across the literature for multiple VME taxa (e.g., Schejter et al. 2016, 2021, Brewin et al. 2020), the inclusion of fish and squid community dynamics into the mix, along with data on marine higher predators (Baylis et al. 2021) means that the Burdwood Bank could theoretically be described as a province in and of itself - highlighting just how important it is to protect and inform conservation management and secure the sustainability of this important marine ecosystem into the future.

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CHAPTER 3

MARINE HIGHER PREDATORS

Image: Rockhopper penguin. Credit: SAERI.

CHAPTER SUMMARY

- The Falkland Islands are a globally significant site for colonial breeding marine higher predators (seabirds and seals) and cetaceans. We assessed how the proposed Marine Managed Areas (MMA) network overlaps with contemporary estimates of marine predator distribution.
- For colonial breeding species (Section 3.1), we collated tracking data for seabirds and seals (1999-2019) and used a combination of kernel density estimation and model-based predictions of spatial usage to quantify overlap between colonial breeding marine predators and proposed Falkland Islands MMAs.
- Recognizing local interest in IUCN Key Biodiversity Areas (KBAs), we also identified potential KBAs (pKBAs) using (1) kernel density-based methods originally designed to identify Important Bird and Biodiversity Areas (IBAs), and (2) habitat preference models.
- The proposed inshore MMA, which extends 3 nautical miles from the Falkland Islands baseline, overlapped extensively with areas used by colonial breeding marine predators. This reflects the dispersed distribution of breeding colonies throughout the Falklands archipelago, and use being highest near these sites due to central-place foraging constraints.
- Up to 45 % of pKBAs identified via kernel density estimation were located within the proposed MMAs. In particular, the proposed Jason Islands MMA (a series of islands within the Falklands archipelago that support large numbers of seals and seabirds), overlapped with pKBAs for 3 species, suggesting it is a KBA hotspot.
- Habitat model predictions for both sampled and unsampled colonies provided less biased estimates, and revealed 72 % of the Falkland Islands Conservation Zone was likely a KBA.
- For species like albatross that travel hundreds of miles, MMAs encompass foraging ranges at certain times of the year, and protect areas around breeding colonies where animals are known to congregate.
- For cetaceans (Section 3.2) We also collated aerial, boat and land-based survey data. Cetacean surveys (2016-2019) were primarily conducted within the proposed Falkland Islands MMAs. Therefore, the majority of cetacean sightings were within the boundaries of the proposed MMAs.
- The most notable exception were sightings of baleen whales to the north of the Falkland Islands, outside of the proposed inshore MMA.
- Given there is limited survey data outside of the proposed MMAs, predictive models are a useful tool to explore probable distribution of cetaceans over larger areas. The predictive models for sei whales and Commerson's dolphins highlight that the probability of occurrence typically declines with distance away from the Falkland Islands coastline. In contrast to Commerson's dolphins and sei whales, the distribution of Peale's dolphins were relatively uniform around the Falkland Islands coastline.
- Predictive models also revealed 'hotspots' of predicted occurrence – where there was a higher probability of finding high numbers of cetaceans. For both Commerson's dolphins and sei whales, the majority of the 'hotspots' fall within the proposed inshore MMA, which supports the importance of the inshore MMA for cetaceans.
- With regard to the designated sei whale KBA, the proposed MMAs encompass 99% of the confirmed sei whale sightings, over 70% of the KBA and, as stated above, the majority of the predicted hotspots. Therefore, the inshore MMA boundaries are likely to be ecologically relevant and will enable the persistence of the biodiversity elements for which the sei whale KBA was designated.
- Importantly, the proposed MMAs will provide enhanced protection for KBAs.
- Ideally, future cetacean surveys could venture beyond the proposed MMA boundaries to understand cetacean abundance outside of proposed MMAs.

3.1 SEABIRDS AND SEALS: OVERLAP WITH PROPOSED MMAS AND IDENTIFICATION OF MARINE KEY BIODIVERSITY AREAS

SUMMARY

- The Falkland Islands are a globally significant site for colonial breeding marine higher predators (seabirds and seals) and cetaceans. We assessed how the proposed MMA network overlaps with contemporary estimates of marine predator distribution. To do so, we collated tracking data (1999-2019) and used a combination of kernel density estimation and model-based predictions of spatial usage to quantify overlap between colonial breeding marine predators and proposed Falkland Islands MMAs. Recognizing local interest in IUCN Key Biodiversity Areas (KBAs), we also identified potential KBAs (pKBAs) using (1) kernel density-based methods originally designed to identify Important Bird and Biodiversity Areas (IBAs), and (2) habitat preference models.
- The proposed inshore MMA, which extends 3 nautical miles from the Falkland Islands baseline, overlapped extensively with areas used by colonial breeding marine predators. This reflects the dispersed distribution of breeding colonies throughout the Falklands archipelago, and use being highest near these sites due to central-place foraging constraints.
- Up to 45 % of pKBAs identified via kernel density estimation were located within the proposed MMAs. In particular, the proposed Jason Islands MMA (a series of islands within the Falklands archipelago that support large numbers of seals and seabirds), overlapped with pKBAs for 3 species, suggesting it is a KBA hotspot.
- Habitat model predictions for both sampled and unsampled colonies provided less biased estimates, and revealed 72 % of the Falkland Islands Conservation Zone was likely a KBA.
- We found that while IUCN KBA criteria are standardised, the methods used to identify areas for assessment against KBA criteria are not standardised for marine predator tracking and survey data. Therefore, there is considerable uncertainty in the p KBA boundaries identified.
- For species like albatross that travel hundreds of miles, MMAs encompass foraging ranges at certain times of the year, and protect areas around breeding colonies where animals are known to congregate.
- New Island is an important site for seabirds, and the waters around New Island might be considered for designation as a National Marine Nature Reserve.

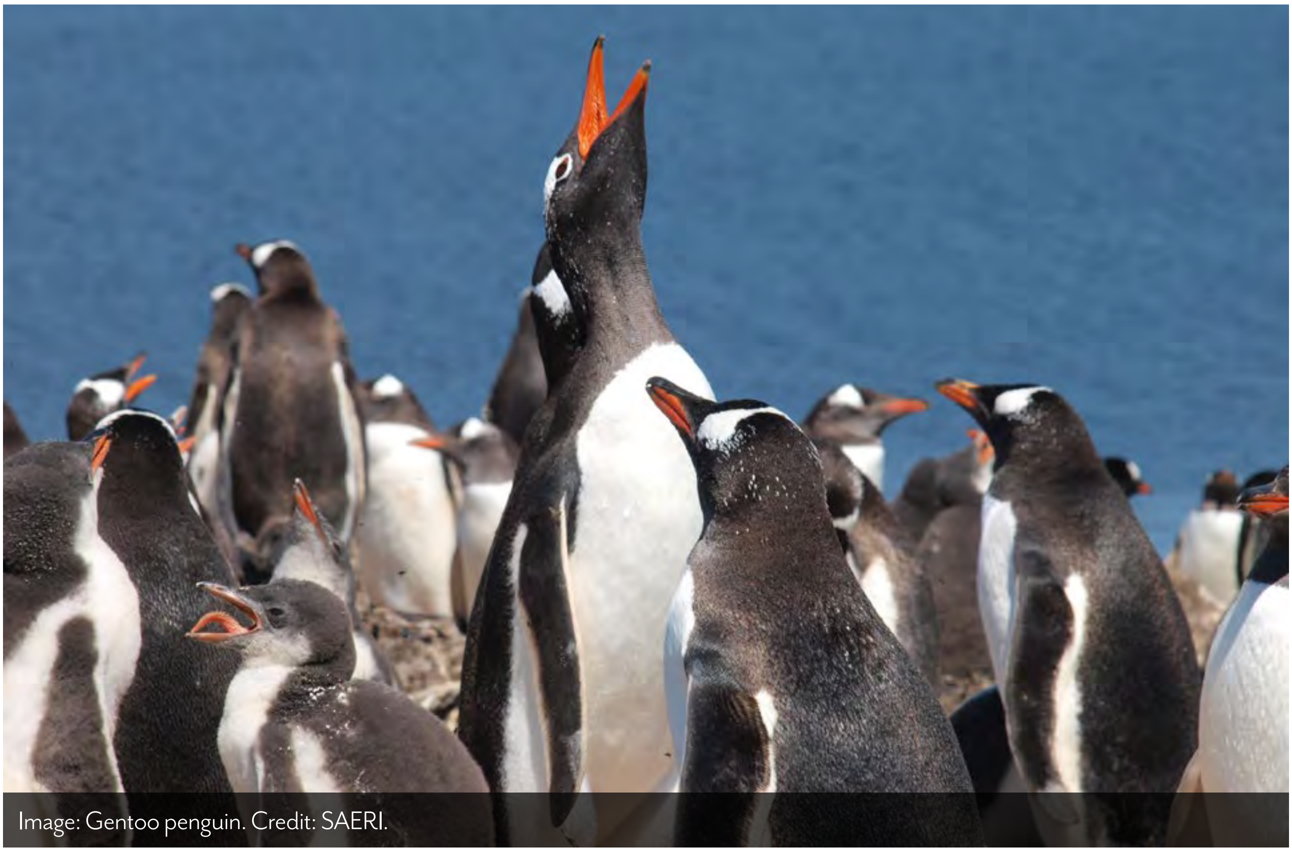
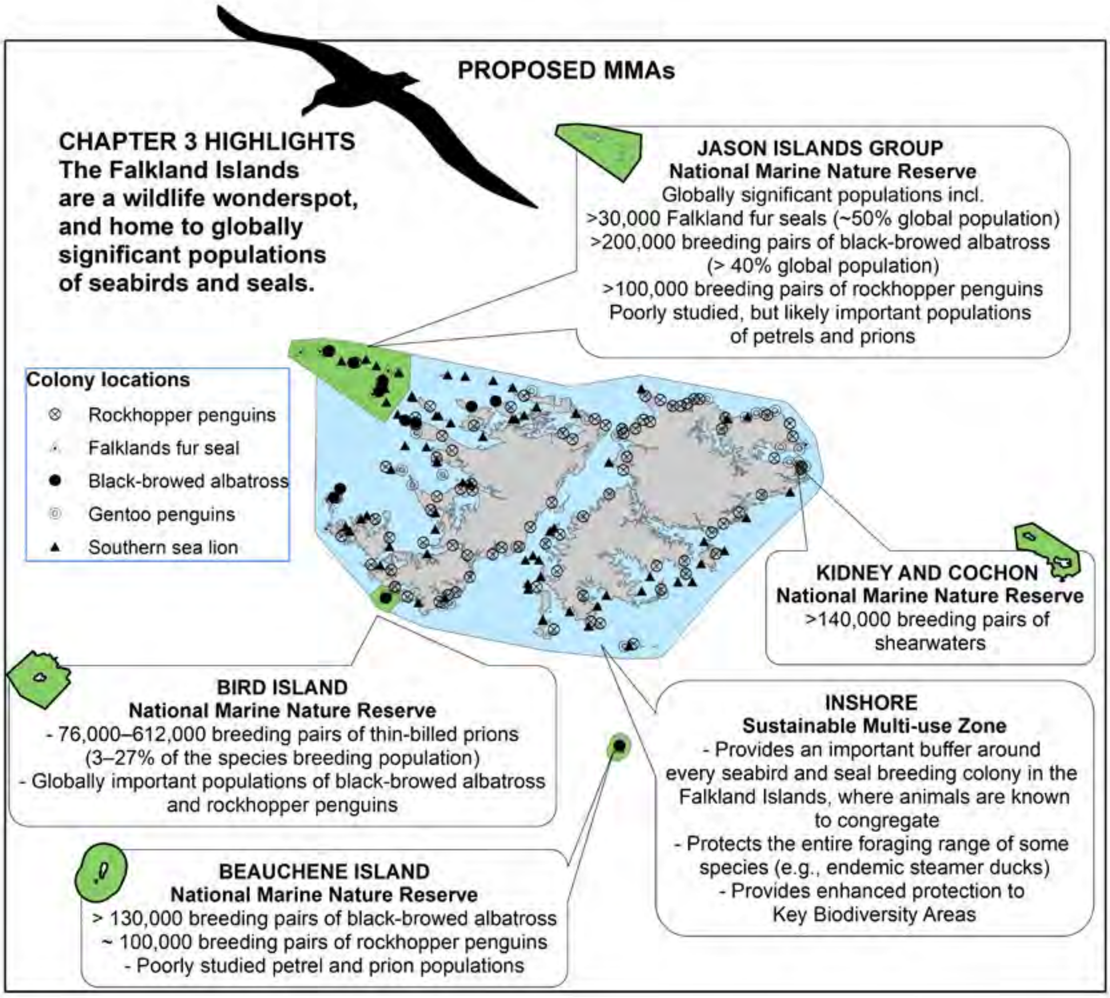


Image: Gentoo penguin. Credit: SAERI.



PROPOSED MMAs

CHAPTER 3 HIGHLIGHTS

The Falkland Islands are a wildlife wonderspot, and home to globally significant populations of seabirds and seals.

JASON ISLANDS GROUP
National Marine Nature Reserve
Globally significant populations incl.
>30,000 Falkland fur seals (~50% global population)
>200,000 breeding pairs of black-browed albatross (> 40% global population)
>100,000 breeding pairs of rockhopper penguins
Poorly studied, but likely important populations of petrels and prions

KIDNEY AND COCHON
National Marine Nature Reserve
>140,000 breeding pairs of shearwaters

BIRD ISLAND
National Marine Nature Reserve
- 76,000–612,000 breeding pairs of thin-billed prions (3–27% of the species breeding population)
- Globally important populations of black-browed albatross and rockhopper penguins

INSHORE
Sustainable Multi-use Zone
- Provides an important buffer around every seabird and seal breeding colony in the Falkland Islands, where animals are known to congregate
- Protects the entire foraging range of some species (e.g., endemic steamer ducks)
- Provides enhanced protection to Key Biodiversity Areas

BEAUCHENE ISLAND
National Marine Nature Reserve
> 130,000 breeding pairs of black-browed albatross
~ 100,000 breeding pairs of rockhopper penguins
- Poorly studied petrel and prion populations

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INTRODUCTION

Some seventy seabird species and 29 marine mammal species have been recorded in Falkland Islands waters (Woods and Woods 1997, Augé et al. 2018). While the Falkland Islands is likely to be an important feeding area for many of these species, the primary focus of this chapter are species that breed in the Falkland Islands, and more specifically, those species for which tracking data is available (Appendix Table S1). The Falkland Islands host globally significant breeding populations of seabirds and seals. For example, approximately 75 % of the global population of black-browed albatross (*Thalassarche melanophris*) breed in the Falkland Islands, 50 % of the South American fur seal population (*Arctocephalus australis australis*), and 33 % of the global population of southern rockhopper penguins (*Eudyptes chrysocome*). Accordingly, fluctuations in breeding numbers at the Falkland Islands impact the global conservation status of these species (Baylis et al. 2013a, 2013b, 2019a). In light of globally significant marine predator populations, it is unsurprising that numerous marine predator priority areas have been identified within the Falkland Islands using approaches such as Important Bird and Biodiversity Areas (IBAs) (Table 3.1) (Falklands Conservation 2006, Augé et al. 2018).

The proposed Falkland Islands Marine Managed Areas (MMAs) were identified through the Assessment of Fishing Closure Areas as Sites (AFCAS) for wider management of the Falkland Islands marine environment process. The proposed MMAs, as the AFCAS name implies, are areas that are closed to fishing or subject to low fishing impact (termed marine wilderness areas in the literature). These areas have irreplaceable biodiversity and are ecologically representative, but presently do not have a legal framework for protection. Ecologically representative means that the design of the proposed MMAs take into account all the different parts of an ecosystem (seafloor, kelp forests, phytoplankton and zooplankton, fish, squid, seabirds, cetaceans etc.), rather than being driven by a single species. Accordingly, the proposed Falkland Islands network of MMAs integrated the best information available at the time on the abundance and distribution of marine predators (Augé et al. 2018). Specifically, this information included 36 species, 12 of which did not breed in the Falklands (e.g., Wandering albatross (*Diomedea exulans*) (Augé et al. 2018). The analysis combined tracking data and at-sea observation data, and mapped core use areas for species. The results highlighted the importance of the inshore area around the Falkland Islands (Fig. 3.1) (Augé et al. 2018). However, there have been considerable advances in our understanding of the at-sea distribution of marine predators breeding at the Falkland Islands since Augé et al. (2018) and the identification of the proposed MMAs.

In addition, the IUCN have recently developed guidelines for applying globally standardised criteria and thresholds for designating Key Biodiversity Areas (KBAs), using IBA criteria to help inform the design of KBA criteria (IUCN 2016, 2019, Smith et al. 2019). KBAs are sites that *"contribute significantly to the persistence of global biodiversity"* and are widely used to help inform systematic conservation planning and in the implementation of Aichi Target 11 (Smith et al. 2019, IUCN 2020). However, marine KBAs have not been assessed for marine predators breeding at the Falkland Islands, which is an impediment to placing the conservation value of the proposed MMAs into a global context for marine predators, and could help to identify other important candidate areas for marine protection. [1]

In this chapter, we build on our early Marine Spatial Planning work (Augé et al. 2018), but compile the most comprehensive marine predator tracking dataset available for the Falkland Islands and quantify overlap (a performance metric) between marine predator at-sea distribution and the proposed Falkland Islands MMAs. Specifically, we test:
(1) Overlap between foraging areas determined from tracking data and proposed MMAs;
(2) Predicted marine predator spatial usage and MMA coverage – that is, we develop habitat model predictions for both sampled and unsampled colonies, because using tracking data alone is biased to the colonies tracked;
(3) Identification of potential areas that could be considered as KBAs (hereafter pKBAs). Although KBAs generate much interest, little attention is given to methods used to identify areas to assess against IUCN KBA criteria. To identify pKBAs, we test various approaches to understand how pKBA boundaries could vary depending on the method used.;
(4) Model-based predictions of pKBAs (as in point 2 – to provide less biased estimates).
(5) Prioritised gap analysis: although important at-sea areas for seabirds and pinnipeds are frequently identified using tracking data, such areas are often biased by non-uniform sampling across species, populations and life history stages. Hence, we also identified priority gaps in the tracking data currently available.

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[1] Falklands Conservation are working with BirdLife International to designate inshore waters around globally important seabird breeding colonies as Key Biodiversity Areas (5 km buffer around breeding colonies). We have not included an overview of these areas because, at the time of writing, they were not designated as KBAs and therefore the delineation of the KBAs might change (i.e., following IUCN KBA guidelines, how these areas would harmonize with the existing sei whale KBA boundaries). These proposed areas do however, fall within the proposed MMA boundaries, given the proposed inshore MMA extends to 3 nautical miles from the Falkland Islands baseline.

HOW DO IUCN KBAs AND PROPOSED FALKLAND ISLANDS MMAs COMPARE?

Key Biodiversity Areas (KBAs)	Marine Managed Areas (MMAs)
Non-statutory. KBAs are administered by the KBA secretariat on behalf of 13 international Non-Governmental Organisations. BirdLife International co-hosts the KBA secretariat and manages the KBA database (https://www.keybiodiversityareas.org/)	Legal framework, nationally and internationally recognised
Initially based on ecological criteria alone (e.g., species aggregations) and based on a single species	Integrate socio-economic constraints and an ecosystem-based approach to marine management (designed to benefit multiple species and habitats, from seafloor sediment, to coral gardens, kelp forests, zooplankton, fish, seabirds, seals and whales)
No management plan or objectives	Management plan & objectives

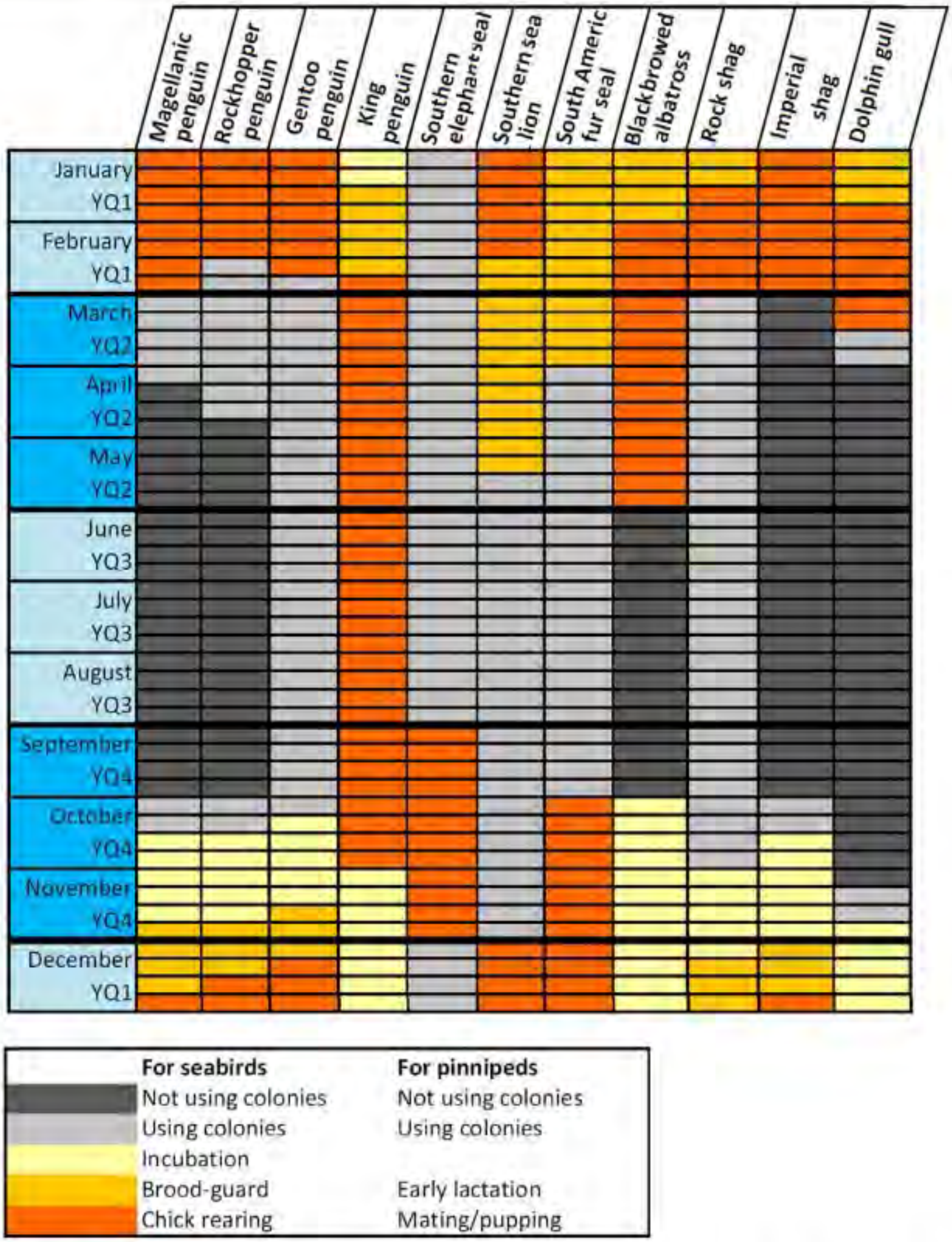
CHALLENGES DELINEATING KBAs FOR SEABIRD AND SEAL TRACKING DATA AND AT-SEA SURVEY DATA

KBA threshold-based criteria are standardised, repeatable, and globally applicable and KBAs facilitate marine conservation by highlighting areas that are globally significant. However, the methods used to identify areas to assess against KBA criteria are not standardised for tracking and survey data.

This means KBA size will vary, sometimes by an order of magnitude, depending on the methods used. Given KBAs might be considered for potential protected areas, it would be useful to understand and quantify uncertainty in areas selected to be assessed against KBA criteria. This is because we want to provide decision makers with reliable data and robust science narrative, which ensure the areas identified as important are well supported. At present, there is no standardised approach to identify KBAs from tracking and survey data.

IUCN KBA guidelines continue to be refined and updated. It is important that the guidelines continue to evolve to ensure KBA guidelines are applied rigorously. The most recent guidelines (IUCN 2020) clarify that species must predictably aggregate at a site to trigger KBA criterion D1a (just one of several criteria, but the one we felt best suited our data). However, predictability is scale dependent and we don't yet know how this definition will apply to tracking data for wide-ranging marine predators that forage on patchily distributed prey. Hence, a range of challenges exist with current methods.

Limitations aside, almost all of our ocean could meet the criteria for being considered as a KBA for marine higher predators (we estimate over 70% of Falkland Islands waters). This is because we are fortunate to have a number of globally significant populations, including 75 % of the global population of Black-browed albatross and 50 % of the global population of South American fur seals, and of course, endemic steamer ducks.



Many species that breed in the Falkland Islands have complex life histories, as is shown by this figure for a select number of seabird and seal species. Some migrate during winter months, like Rockhopper and Magellanic penguins, while others are resident, like fur seals and gentoo penguins. Source: Augé et al. 2018.

METHODS

The AFCAS study prioritised four main marine wilderness areas as potential MMAs (Brickle et al. 2019). These are the Burdwood Bank, which includes two potential MMAs (Fig 2), selected due to benthic biodiversity and importance as foraging habitat for migratory species (Augé et al. 2018); MMAs around the Jason Islands (recognised as a terrestrial KBA) and Beauchêne Island selected as seaward extensions of globally important breeding colonies of seabirds and seals where animals are known to congregate (e.g. Granadeiro et al. 2018) (Fig 3.2, Table 3.2); and an inshore MMA around the Falkland Island coastline, which is near pristine owing to fishing restrictions within 3 nautical miles of the Falkland Islands coastal baseline since 1989 (Fig 3.2, Table 3.2). A further rationale for the proposed inshore MMA was to provide a buffer between marine predator breeding colonies and human activities at-sea.

Observed marine predator spatial usage and MMA coverage

To assess overlap between marine predators and proposed MMAs, we used the tracking dataset described in Baylis et al. (2019), plus additional imperial shag (*Leucocarbo atriceps*) and rockhopper penguin GPS location data and Argos location data for South American fur seals (Fig 3.3, Appendix S1). Our focus was on non-migratory movements of marine predators. Prior to analysis, location data were projected into Lambert Azimuthal Equal Area projection. In brief, GPS locations for flying seabirds were speed filtered to remove locations associated with unrealistic speeds (>20 m/s) (Baylis et al. 2019b). Location data were then linearly interpolated at hourly intervals (Baylis et al. 2019b). Spatial errors associated with Argos data are relatively high and unpredictable. After filtering Argos locations to remove speeds unrealistic for pinnipeds (>3 m/s), we estimated locations hourly using a continuous-time correlated random walk model, fitted using the R package 'crawl' (v2.1.1) (Johnson et al. 2008). The model accounted for location error and uncertainty in the path the animal may have followed between fixes. To summarize the observed distribution of individuals at-sea, we split location data into *data groups* according to species, colony, breeding status (breeding, not-breeding) and where appropriate, breeding stage or season (Appendix S1: Table S1). We then estimated the utilization distribution (UD) of each data group by calculating the kernel density of locations within that group using the R package adehabitatHR. We used a land mask to prevent kernels from being smoothed over land. The smoothing parameter *h* (i.e., the width of the bivariate normal kernel placed over each location) was calculated based on First Passage Time (FPT) analysis (Lascelles et al. 2016). We then calculated the overlap between each data group's 50 % UD cumulative volume contour (assumed to represent core foraging area), and each proposed MMA.

Predicted marine predator spatial usage and MMA coverage

It is impractical to track seabirds and pinnipeds from all Falkland Islands breeding colonies. To estimate how the proposed MMAs overlapped with marine predators more generally, we therefore used the Generalized Additive Models (GAMs) from Baylis et al. (2019b) to predict the UDs of animals from both observed and unobserved colonies (for a detailed description of the modelling approach see (Baylis et al. 2019b). Briefly, space usage was modelled as functions of dynamic and static environmental indices that described habitat, including sea surface temperature, bathymetry, and eddy kinetic energy (Baylis et al. 2019b). We standardised each predicted UDs to sum to 1, and calculated predicted core foraging areas based on 50% UD contours using the getverticeshr function in adehabitatHR (Calenge 2006).

THE PATAGONIAN SHELF IS VAST AND VASTLY IMPORTANT TO MARINE PREDATORS

Briefly, we collated tracking data (1999-2019) and used several approaches to identify areas for assessment against KBA criteria (a combination of kernel density estimation methods originally designed to identify Important Bird and Biodiversity Areas (IBAs) and model-based predictions).

It should come as no surprise that much of the Patagonian Shelf around the Falkland Islands is important. In fact, depending on the methods used, over 70% of the Falkland Islands waters could qualify as a KBA. This is because the Falklands are home to numerous and globally significant populations of seals and seabirds – many species of which breed almost ubiquitously around the Falklands.

Identification of pKBAs

Tracking data

Baylis et al. (2019b) concluded that large areas of the Patagonian Shelf were potentially important marine predator habitat. It is difficult to apply specific, area-based management recommendations to the entire shelf area around the Falkland Islands, even if this is an accurate representation of important at-sea areas (see also Augé et al. 2018). Hence, to identify areas of global importance, we identified pKBAs based on IUCN KBA Criterion D1a (demographic aggregations ≥ 1 % of the global population size) (IUCN 2016), and then quantified pKBA overlap with the proposed MMAs.

To identify pKBAs based only on tracking data from sampled colonies, we used the methods published in Lascelles et al. (2016), which were developed for flying seabirds, but recently adapted to penguins and seals (Dias et al. 2018, Handley et al. 2020). We selected data groups that either had ≥ 10 individuals or ≥ 15 foraging trips (Handley et al. 2020). We re-analyzed these data using methods described above (*Observed marine predator spatial* *usage and MMA coverage*), but interpolated locations to 30 min intervals, given the dataset was dominated by flying seabird GPS data that was sampled at 19 ± 10 min intervals on average. Analysis was run at the foraging trip level when sample size for individuals was < 20. The analysis involved four main steps:

(1) Calculate the *h* value used in the kernel analysis, which defines the smoothing parameter

The *h* value specifies kernel size and therefore ultimately the size of the final polygon to be assessed against KBA criteria. The novel approach outlined in Lascelles et al. (2016), uses the scale that foraging animals interact with their environment as the *h* value. We defined the *h* value using two methods (i) Using FPT analysis, we defined *h* as the median (rather than mean used by Lascelles et al. (2016)) scale of Area Restricted Search, calculated using the function scaleARS with a maximum search scale that was equal to maximum foraging trip distance (Lascelles et al. 2016, Dias et al. 2018). Assumptions of this method are that animals display Area Restricted Search and that their movement was tracked at high enough resolution to resolve this behaviour. This is unlikely for datasets with low temporal resolution location data (Bradshaw et al. 2007, Weimerskirch et al. 2007). (ii) Alternatively, therefore, we defined *h* as the median standard deviation of the variance of longitude and latitude for each foraging trip, while taking into account the number of locations (hereafter, the variance method) (Beal et al. 2020). For brevity, we did not consider other simple ways to define *h*, such as the log of maximum foraging trip distance (Beal et al. 2020).

The choice of interpolation interval could influence h irrespective of method used, because lower sampling intervals can reduce apparent movement complexity (Bradshaw et al. 2007). To understand how our choice of data interpolation interval influenced the size of polygons to be assessed against KBA criteria, we used high resolution GPS data to model the relationship between location interval and KBA size. We tested the significance of this relationship using Generalized Additive Mixed Models (GAMMs), given data dependency structure and patterns in residuals when applying Linear Mixed Models.

(2) Calculate core UD volume contours via kernel density analysis using the *h* value

To identify kernels from individuals that would contribute to polygon sites for assessment against KBA criteria, we extended the Lascelles et al. (2016) "batch_UD" function to avoid kernels being projected over land and to calculate individual-level UDs and then standardised these to estimate population-level usage.

(3) Estimate how representative the data are of the population

To assess whether data were representative of the colony tracked, we used the "bootstrap" function (Lascelles et al. 2016). Briefly, this randomly selects an increasing number of individuals or foraging trips, calculates the core foraging area and then models this as a function of sample size via nonlinear asymptotic regression. The assumption is that a sample is sufficiently representative if the representativeness value is ≥ 70 %.

(4) Identify where core areas for individuals in each data group overlap most frequently and assess this area against KBA criteria.

To quantify the proportion of individual 50 % UD that overlapped, we used a 0.1° grid and the function "polycount" to identify overlapping polygons (Lascelles et al. 2016). We then used the "thresholdRaster" function to identify areas used by 10 %, 12.5 % or 20 % of the tracked population, depending on whether the tracking dataset representativeness value was > 90 %, 80 – 90 % or 70 – 80 %, respectively (Lascelles et al. 2016). To quantify whether the resulting areas qualified for KBA status – specifically, IUCN KBA Criterion D1a (IUCN 2016) - we estimated the population number within the identified polygon by multiplying colony size by the proportion of the overlapping tracked population by a correction factor. Specifically, we used a correction factor of 0.9, 0.75 or 0.5, depending on whether the representatives value was > 90 %, 80 - 90 % or 70 - 80 %, respectively (Lascelles et al. 2016). We did not smooth polygons into management units, because our intention was not to designate KBAs, but rather to understand how pKBAs overlapped with MMAs.

The 50 % UD of a data group will usually be larger than its KBA using the Lascelles et al. (2016) method, because the method outputs a conservative boundary for assessment against relevant criteria. How KBAs relate to the 50% UD may not be clear to decision makers, yet has important considerations for management. Specifically, the 50% UD has direct biological interpretability. It's where, on average, the population spends 50% of its time. If the KBA covered the 50% UD entirely, then animals in that population would spend an average of 50% of their time within the KBA. If the area that the KBA covers is smaller, then animals will spend less of their time within the KBA. Hence, we assessed how each data groups pKBAs overlapped with its 50 % UD. We also quantified overlap between KBAs identified and all other datasets, irrespective of species, colony location and temporal differences between a pKBA and other data groups. It is valid to question how a population will be protected by a KBA based on data from one colony, or how a KBA benefits other species, given the identification of static protected areas for management and conservation are a major focus of marine conservation efforts, including at the Falkland Islands.

Model-based predictions of KBAs

Baylis et al. (2019) predicted the probability of space use at-sea for marine higher predators breeding at the Falkland Islands from both tracked and untracked colonies; offering a potentially alternate route for marine KBA identification. For each colony in each data group, we multiplied the probability of space use by colony size (number of seabird breeding pairs using 2010 census data or number of fur seal pups as a proxy for breeding females using 2018 census data) (Baylis et al. 2013a, 2013b, 2019a). We then summed cells across grids to arrive at an estimate of the expected density of animals from all colonies across the study area. Finally, we identified cells where n animals ≥ 1 % of the global population of individuals (KBA criterion D1a; taken as the species global breeding pair number multiplied by two for seabirds, or the species global pup production estimate for pinnipeds).

Prioritised gap analysis

We used the “conservation scores” from Augé et al. (2018) to prioritize 24 seabird and pinniped species based on IUCN Red List status and Falkland Islands population size, as a % of global population (Augé et al. 2018). Specifically, scores for IUCN Red List status ranged from 0 to 3 (Least Concern to Critically Endangered, respectively) and 1 to 5 for population size (1 = < 1 % of global population and 5 = endemic to the Falkland Islands), with 8 being the maximum score. We identified globally important breeding colonies where tracking data were lacking.

RESULTS

In total, our dataset comprised 707 individuals and 1,934 foraging trips. Maximum foraging trip distance by species ranged from 46 km for chick-rearing imperial shags to 1,325 km for incubating black-browed albatross (Appendix S1: Table S1).

Overlap between observed core areas and proposed MMAs

Overlap between the 50 % UD for each data group and the proposed MMAs (i.e., % of core foraging areas that were encompassed by MMAs) was low (median overlap was 0 (0 - 0.7) %) but values ranged from 0 % to 97 % depending on species and data group (Table 3.3). The proposed inshore MMA had the largest overlap across all species, with the exception of southern elephant seals (median 13.8 (4.6 – 18.8) %). The 50% UD of elephant seals were restricted to the Patagonian Shelf slope, and therefore did not overlap with any of the proposed MMAs.

Overlap between predicted core areas and proposed MMAs

The predicted distribution of marine predators within the Falkland Islands Conservation Zones were dispersed across 46,757 km² and covered 57 % of the Falkland Islands Conservation Zones (Fig 4; estimate based on the predicted 50% UD). Accordingly, overlap with the proposed MMAs for a number of wide-ranging species was relatively low. The greatest overlap between the predicted distributions of predators was with the proposed inshore MMA (median 0.1 (0 – 2.9) %, range 0 – 36 %) (Table 3.4).

Identification of pKBAs

Tracking data

Most data groups did not meet the KBA Criterion D1a, because demographic aggregations were < 1 % of the global population size. In addition, gentoo penguins tracked from Pebble Island and New Island were excluded because tracking data had low population representativeness scores (57 % and 69 %, respectively). Analysis using h values from the FPT method (h = 16.5 to 18) failed for black-browed albatross tracked during the incubation period (n = 107 individuals) (individual overlapping polygons were < 10 %), but succeeded using the variance method (h = 30.5 to 40.6). The interval at which location data were interpolated influenced polygon size and therefore pKBA size. Specifically, using the FPT method to calculate h value, we found polygons were smaller for flying seabird GPS data at low sampling frequency (reducing the sample interval reduced h, presumably because the apparent track became less tortuous) (GAMM, n = 409, edf = 4.2, F = 19, $p < 0.001$) (Fig 3.4). For example, polygons assessed against KBA criteria for sooty shearwaters ranged from > 3,000 km² to < 2,000 km² (Fig 3.4). In contrast, using the variance method, we found polygons that represented pKBAs were smaller at high sampling frequencies (i.e., variance in latitude and longitude was smaller) (GAMM, n = 528, edf = 8.5, F = 95, $p < 0.001$) (Fig 3.5).

We successfully identified pKBAs for black-browed albatross (Steeple Jason Island, Beauchêne Island, New Island), rockhopper penguins (Steeple Jason Island), Sooty shearwaters (Kidney Island) and adult female South American fur seals (West Cay Island) (Fig 3.6). Representativeness scores for these data groups ranged from 74 % to 99 %. Irrespective of the methods used to define the h value, KBA analysis highlighted the area to the north-west of the proposed Steeple Jason MMA as a biodiversity hotspot, where pKBAs for three species overlapped (rockhopper penguin, South American fur seal, black-browed albatross) (Fig 3.2, Fig 3.7). However, the polygon size assessed against KBA criteria varied depending on the method used to define h values. Specifically, the total area covered by all pKBAs were 8 times smaller using the FPT method, when compared to the variance method (Fig 3.1, Fig 3.7, Appendix S1).

In total, pKBAs within Falklands waters covered 2.7 % (12,644 km²) of the Falkland Islands Conservation Zones using the FPT method, or 16.2 % (467,547 km²) when using the variance method to define h (Fig 3.2, Fig 3.7). The largest overlap was between the proposed Jason Islands MMA and inshore MMA (Appendix S1: Table S1). Overlap between pKBAs and the proposed Jason Islands MMA (percentage of the pKBA within the MMA) ranged from 12.4 - 15.3 % for South American fur seals, 24.4 - 25.5 % for rockhopper penguins and 9.5 - 44.7 % for black-browed albatross depending on whether the FPT method or variance method were used (Appendix S1: Table S2). Overlap between pKBAs and the proposed inshore MMA ranged from a median of 23.9 (15.8 –

31.4) % using the FPT method, to a median of 8.7 (6.9 – 17.4) % using the variance method (range 0 % for incubating black-browed albatross at Steeple Jason Island to 33.5 % for lactating South American fur seals) (Appendix S1: Table S2).

Model-based predictions of pKBAs

Potential KBAs estimated from model-predicted UD, encompassed 72% of the Falkland Islands Conservation Zone (Fig 3.4). The largest overlap between predicted KBAs and MMAs was between the proposed inshore MMA (median 7.0 (4.4 - 8.5) %) Appendix S1: Table S1).

Overlap in geographic space between pKBAs and observed and predicted core areas

Overlap (percentage of the core area within pKBA) between pKBAs and the 50 % UD generated for individual data groups that triggered the pKBAs were variable. For KBAs defined using the FPT analysis, overlap ranged from 13 – 100 % (median 41.9 (24.4 – 87.2) %). Using the variance method, pKBA overlap with 50 % UD ranged from 14 – 100 % (median 88.9 (28.3 - 97.1) %) (Appendix S1: Table S3).

We also compared the 50 % UD of all data groups and species to individual pKBAs, to assess whether pKBAs were representative of other Falkland Islands marine predators. Overlap ranged between 0 % and 30 % (median 0 (0 – 2.3) %) for pKBAs identified using the FPT method and between 0 % and 68 % (median 1.8 (0 – 11.9) %) for KBAs identified using the variance method (Appendix S1: Table S3). On average, the pKBAs encompassed less marine predator UDs than the inshore MMA (median overlap between UDs and proposed inshore MMA was 13.8 (4.6 – 18.8) %). Overlap between pKBAs identified using tracking data alone, and the predicted 50 % UD of marine predators ranged between 0 and 15 % (Appendix S1: Table S4).

Prioritised gap analysis

Data were lacking for small petrels and prions, which are difficult to census and track, but anecdotally, the Falkland Islands have large and potentially globally significant populations (Appendix S1: Table S5). The species that ranked highest and therefore would improve the comprehensiveness of tracking data, include endemic Falkland steamer ducks (*Tachyeres brachypterus*) and the largest breeding populations of rockhopper penguins (*Beauchêne* Island and Steeple Jason Island), South American fur seals (East Cay, West Cay and Seal Rocks) and gentoo penguins (Saunders Island, Pebble Island) (Appendix S1: Table S5).

DISCUSSION

Proposed MMAs

Marine predators breeding at the Falkland Islands overlapped more extensively with the proposed inshore MMA, when compared to other MMAs. This reflected the widespread breeding distribution of a number of colonial breeding marine predator species around the Falkland coastline, and the fact that central place foraging animals have to travel through this coastal zone when commuting between breeding colonies and feeding areas. The wide-ranging movements of most species (10s-1,00s of km), resulted in a high proportion of home ranges not being captured by the proposed MMAs, even around the colonies they were intended to protect. Despite this mis-match in scale between proposed MMAs (which necessarily aim to balance ecological, economic and social factors), and the scale at which wide-ranging species used the marine environment, the proposed MMAs encapsulate areas around breeding colonies where animals are known to congregate (e.g., to preen), and the foraging areas of a number of other species that were not included in our study, but are known to forage nearshore. For example, rock shags (*Phalacrocorax magellanicus*) breeding at the Falkland Islands travel an average distance from land of 0.4 km, and a max distance of 3.6 km, flightless steamer ducks are likely to spend the majority of the annual cycle within the inshore MMA, and similarly, Peales dolphins (*Lagenorhynchus australis*) are thought to spend a high proportion of their time within nearshore coastal waters (Augé et al. 2018, Franchini et al. 2020). The proposed inshore MMA also includes much of the Falkland Islands kelp forests, which play an important role in nutrient cycling, carbon sequestration and are crucial to larval life history phases of squid and fish, important to both fisheries and higher marine predators (Krause-Jensen and Duarte 2016). Hence, while the extent of proposed MMAs are limited in the context of marine predator foraging ranges, the proposed MMAs have multiple biodiversity conservation benefits and, given the proposed MMAs are near pristine marine wilderness areas, they are likely to be important sites for a diverse range of taxa and habitats, including unique benthic biodiversity and undisturbed marine sediments. Crucially, the proposed MMAs would provide a pathway for long-term commitment that is required to ensure the success of a protected area and establish the legislative framework and legal structure for other priority areas, such as non-statutory KBAs, to be considered as future MMAs (Esch 2006).

What about Key Biodiversity Areas?

One aim of our analysis was to explore how potential marine predator KBAs could inform the proposed Falkland Islands network of MMAs and identify other important candidate areas for marine protection. This was in-part motivated by the keen local interest in KBAs. We identified marine areas that were considered globally important using a standard set of criteria, which complements recent studies highlighting that much of the Patagonian Shelf around the Falkland Islands is used intensively by seabirds and pinnipeds and is therefore presumably necessary for their persistence (Augé et al. 2018, Baylis et al. 2019b). Although most pKBAs extended well beyond the proposed MMAs, up to 45 % of some pKBAs were captured within proposed MMAs. In particular, the proposed Jason Islands MMA (and surrounding ocean) was a pKBA hotspot given pKBAs for multiple species overlapped, and because the proposed Jason Islands MMA encompassed globally significant breeding populations of black-browed albatross, rockhopper penguins and South American fur seals (Baylis et al. 2013b, 2019a). Given the large breeding populations seabirds and seals, the area surrounding the proposed Jason Islands MMA, and Beauchêne Island MMA might be considered for any future MMA planning, while New Island could be considered for designation as a National Marine Nature Reserve. The proposed Burdwood Bank MMA also encompassed a designated KBA for South Georgia-breeding wandering albatrosses listed as Endangered on the IUCN Red List (Handley et al. 2020). Hence, pKBAs were useful in supporting and informing the proposed MMAs, and highlighted areas outside of the proposed MMAs that may be important for conservation planning and management. Collating tracking data to assess against KBA criteria was also useful in identifying data gaps and highlighted species and sites where data were deficient, such as the largest regional populations of rockhopper penguins, gentoo penguins, small petrels and South American fur seals, among many other species.

Given KBA site identification is based on criteria and thresholds that identify areas contributing significantly to global biodiversity, the initial delineation of KBA boundaries are based on biodiversity related elements alone (IUCN 2019). However, the IUCN KBA standards (IUCN 2016, 2019) offer guidance on how final KBA boundaries may also consider socio-economic factors. In the context of the Falkland Islands, reconciling the very large spatial extents of KBAs (irrespective of the different methods used), into systematic MMA planning is challenging, but could, for example, involve selecting a small number of KBAs around the Falkland Islands, such as Beauchêne Island, or focus on marine areas adjacent to globally significant breeding colonies (i.e., buffers around colonies). However, some pKBAs failed to encompass a high proportion of the inferred distribution of predators across the whole Falkland Islands archipelago, and therefore, if these alone were utilized, this could lead to conservation priorities being misallocated. Alternatively, KBAs could inform marine management by, for example, being integrated into Marine Spatial Planning toolboxes, and highlight marine areas outside of MMAs where more rigorous impact assessments are required for new activities (McGowan et al. 2017).

Nevertheless, the pKBAs that we identified must be interpreted with caution. Tracking data were inevitably imperfect and biased by tracking effort. Despite collating the most comprehensive dataset to date for the Falkland Islands, temporal data coverage for some species were limited, sample sizes were typically small, and considerable gaps existed in breeding colonies (and age-classes) tracked. Hence, the pKBAs we identified using the Lascelles et al. (2016) methods, informed us of where marine predators were tracked from, but not necessarily where they occur and might not be representative of the whole population. Achieving better coverage requires representative tracks from all colonies at which species achieve globally important numbers. Predictive models can address limitations associated with geographic bias in tracking data and our models revealed that much of the Patagonian Shelf and most of the proposed MMAs may qualify as a KBA based on ecological boundaries alone – although the results from the predictive models are not without caveats and limitations (see Baylis et al. 2019). It would be useful to further refine IUCN KBA guidelines to help standardise how users might incorporate predictive models (Laffoley et al. 2019). Our tracking data were also insufficient to evaluate whether a KBA around a given location would consistently afford protection across seasons and years, because for most species, only a relatively narrow temporal snapshot has so far been obtained. Indeed, the limited overlap between 50 % UD and pKBAs based on tracking data for some species, suggests pKBAs identified using the Lascelles et al. (2016) methods represented commuting corridors near the colony, rather than distant foraging areas, where individuals might face more immediate threats, such as operational interactions with fisheries. Again, our predictive models overcame some of these limitations, but they also suffer from the same temporal bias, given they are based on tracking data limited to the austral summer breeding season for most species. Furthermore, although the Lascelles et al. (2016) methods have recently been used to identify polygons for assessment against KBA criteria (Handley et al. 2020), IUCN KBA guidelines continue to be refined and updated (IUCN 2019, 2020). The most recent guidelines clarify that species must *predictably aggregate* at a site to trigger KBA criterion D1a (IUCN 2020). However, given predictability in the marine environment is dependent on spatiotemporal scales, it is not yet explicit how this definition will be applied to tracking data for wide-ranging marine predators that forage on patchily distributed prey. Therefore, we acknowledge that not all sites identified as pKBAs will necessarily qualify as a KBA under criterion D1a.

The second challenge encountered was that, despite having a large sample size of > 100 black-browed albatrosses, our KBA analysis failed for the incubation period using the FPT method to define the kernel smoothing parameter h (Lascelles et al. 2016). Ideally, knowledge of species movement ecology could facilitate informed decisions about *h* values that are sensible to use. One pragmatic solution was to use a h value defined by the median variance of latitude and longitude across foraging trips – although this typically generated larger polygons and therefore KBAs (total pKBA area covered was 8 times larger when compared to the FPT method). Given the ongoing disagreement about how best to define *h* for the analysis of animal space use data (Fieberg 2007), an even simpler and arguably more objective method would be to use the same value of h for all individuals and populations.

The third challenge was that pKBAs identified using the Lascelles et al. (2016) methods were based on estimated UDs, which in

Image: Jason Islands. Credit: SAERI.

addition to the *h* value, are sensitive to other, often arbitrarily selected values. These include the value chosen to represent core spatial usage (typically 50 %), and the temporal scale of data interpolation (typically 30 mins or 1 hour). We acknowledge that a simple, pragmatic methodology is advantageous, as is the ease at which methods can be adapted, improved and extended beyond flying seabirds (Dias et al. 2018, Handley et al. 2020). However, given the polygons identified to be assessed against KBA criteria varied by > 1,000 km^2 based on the interpolation interval alone, further testing and optimization of key assumptions, along with a measure of uncertainty associated with polygon boundaries, would reduce the ambiguity we encountered in KBA boundary delineation using the Lascelles et al. 2016 methods, and better serve the standardised, repeatable, and globally applicable threshold-based criteria of KBAs.

Conclusions

Clearly, spatial limitations of the proposed MMAs exist in relation to wide-ranging species that travel distances of 100's to >1000 km. That is, the MMAs do not encompass the entire foraging range of several species. However, they do benefit wide-ranging species by providing a buffer around breeding colonies where animals are known to congregate (Granadeiro et al. 2011). They also protect near-pristine benthic habitats and encompass the foraging ranges of many other nearshore marine predators, including shags, endemic steamer ducks, and Commerson's dolphins, as well as the majority of the predicted hotspots of sei whales (described below). For wide-ranging species that often travel beyond national jurisdictions, management could focus on large-scale regulations that are not area specific, including bycatch regulations, such as those being coordinated by The Agreement on the Conservation of Albatrosses and Petrels (**ACAP**).

The proposed MMAs also encompassed some pKBAs. However, our analysis highlights that it is inherently difficult to base MMAs on pKBA boundaries. This is because (i) the methods used to identify KBAs for tracking and survey data are yet to be validated, (ii) with just a limited number of species included in our analysis, over 70 % of Falklands waters are potentially a KBA, which reflects the fact that the Falkland Islands are home to numerous globally significant populations of seals, seabirds and indeed cetaceans (see also section 3.2). Reconciling the very large spatial extents of pKBAs into systematic MMA planning and protected area management remains challenging.

In total, the proposed MMAs would protect about 15% of the Falkland Islands Conservation Zones (i.e., Exclusive Economic Zone), allowing the Falkland Islands to make great strides towards contributing to the **2010 Aichi Biodiversity Target** of 10% ocean protection (and the proposed **2030 Target of 30%**). The proposed MMAs, if designated, would also establish the policy and legislative framework for marine protection, which should pave the way for any future designations, facilitate the management and conservation of globally significant populations of marine predators, including enhanced protection for any designated KBAs, and usher in a new era of ecosystem-based management.

PROPOSED MMAS AND MARINE PREDATORS

Despite limitations highlighted in our technical document for wide-ranging species that travel 100's to >1000 km, there is much to celebrate. The proposed MMAs include the Falkland Islands kelp forests, which play an important role in nutrient cycling, carbon sequestration and are crucial to larval life history phases of squid and fish, important to both fisheries and higher marine predators.

They protect near-pristine benthic habitats and encompass the foraging ranges of many marine predators, including shags, endemic steamer ducks and Commerson's dolphins, encompass many of the predicted hotspots of sei whales, while benefiting other wide-ranging species by providing a buffer around breeding colonies where animals are known to congregate and nearshore foraging areas.

In total, these areas would protect about 15% of the Falkland Islands Conservation Zones (i.e., Exclusive Economic Zone), allowing the Falkland Islands to make great strides towards contributing to the 2010 Aichi Biodiversity Target of 10% ocean protection and the proposed 2030 Target of 30%.

The proposed MMAs, if designated, would also establish the policy and legislative framework for marine protection, which will pave the way for future designations, facilitate the management and conservation of globally significant populations of marine predators, and usher in a new era of ecosystem-based management.

Table 3.1. Sites designated as Important Bird and Biodiversity Areas (IBA) by BirdLife and Falklands Conservation (www.datazone.birdlife.org/).

IBA Code	IBA name		
FK001	Beauchêne Island	**FK012**	Passage Islands Group
FK002	Beaver Island Group	**FK013**	Pebble Island Group
FK003	Bird Island	**FK014**	Saunders Island
FK004	Bleaker Island Group	**FK015**	Sea Lion Islands Group
FK005	Elephant Cays Group	**FK016**	Speedwell Island Group
FK006	Hummock Island Group	**FK017**	West Point Island Group
FK007	Jason Islands Group	**FK018**	Bull Point
FK008	Keppel Island	**FK019**	Hope Harbour, West Falkland
FK009	Kidney Island Group	**FK020**	Seal Bay, East Falkland
FK010	Lively Island Group	**FK021**	Volunteer Point
FK011	New Island Group	**FK022**	Bertha's Beach

Table 3.2. Terrestrial breeding colonies of tracked species that fall within proposed Marine Managed Areas (MMAs). Specifically, the percentage of the Falkland Islands breeding population and the global population (calculated from breeding pairs or breeding females for seals) for select species where reliable population data were available. Population data for Southern sea lions are sparse, with the exception of the Falkland Islands (Baylis et al. 2015). We used 111,250 breeding Southern sea lion females to derive the % of the global population (half the estimated adult component of the sea lion population). There are no breeding populations within the proposed Burdwood Bank MMAs.

		Jason Islands MMA		**Inshore MMA**		**Beauchêne Island MMA**	
Flying seabirds	**IUCN Status**	**% Falklands population**	**% global population**	**% Falklands population**	**% global population**	**% Falklands population**	**% global population**
Black-browed Albatross	LC	55.2	38.2	71.2	49.0	28.8	19.9
Sooty Shearwater	NT	0.0	0.0	100	3.1	0.0	0.0
Penguins							
Gentoo penguin	LC	8.8	0.3	99.5	31.9	0.5	< 1
King penguin	LC	0.0	-	100	< 1	0.0	0.0
Rockhopper penguin	VU	42.4	15.5	66.6	24.3	33.4	12.2
Pinnipeds							
Southern sea lion	LC	7.3	< 1	99.9	3.7	0.1	< 1
South American fur seal	LC	97.0	46.7	84.2	48.0	0.0	0.0
Southern elephant seal	LC	0.0	0.0	100	< 1	0.0	0.0

Table 3.3. Overlap (% area) between core foraging areas for each data group (50 % utilization distribution) and proposed Marine Managed Areas.

Species	Group	Burdwood Bank 1 (NMNR)	Burdwood Bank 2 (SMZ)	Beauchêne Island	Inshore	Jason Islands
Flying seabirds						
Black-browed albatross	chick-rearing	0	0	0.4	20	3.2
Black-browed albatross	incubation	0	0	0.1	3.7	0.8
Imperial shag	chick-rearing	0	0	0	97.1	28.3
Sooty shearwater	chick-rearing	0	0	0	15.3	0
Penguins						
Gentoo penguin	summer	0	0	0	42.7	0
Gentoo penguin	non-breeding	0	0	0	9.4	0.1
King penguin	chick-rearing	0	0	0	1.7	0
Magellanic penguin	summer	0.2	0.2	0.1	7.3	0
Rockhopper penguin	chick-rearing	0	0	0	2.7	0
Rockhopper penguin	incubation	0	0	0	13.7	0
Pinnipeds						
South American fur seal	adult female - winter	0	0	0	19.9	5.3
South American fur seal	adult female - spring	0	0	0	15.4	6.0
Southern sea lion	adult female - summer	0	0	0	13.8	0
Southern elephant seal	pre-moult female	0	0	0	0	0

Table 3.4. Overlap (% area) between predicted distribution of marine predators (50 % utilization distribution) and proposed Marine Managed Areas. Imperial Shags were not included because population data does not exist.

Species	Group	Burdwood Bank 1 (NMNR)	Burdwood Bank 2 (SMZ)	Beauchêne Island	Inshore	Jason Islands
Flying seabirds						
Black-browed albatross	chick-rearing	0.2	0.2	0.0	5.8	0.5
Black-browed albatross	incubation	0.0	0.0	0.0	3.3	0.4
Sooty shearwater	chick-rearing	14.7	16.8	0.0	3.2	0.0
Penguins						
Gentoo penguin	incubation/chick-rearing	0.0	0.0	0.0	35.9	3.4
Gentoo penguin	non-breeding	0.0	0.0	0.1	13.6	1.3
King penguin	chick-rearing	0.0	0.0	0.0	5.5	0.2
Magellanic penguin	summer	0.0	0.0	0.0	4.5	0.4
Rockhopper penguin	chick-rearing	0.2	0.2	0.0	5.8	0.5
Rockhopper penguin	incubation	0.0	0.2	0.1	9.8	0.9
Pinnipeds						
South American fur seal	adult female - winter	0	0	0	8.8	1.2
South American fur seal	adult female - spring	0	0	0	14.2	1.9
Southern sea lion	adult female - summer	0	0	0.3	18.5	3.3
Southern elephant seal	pre-moult female	0	0	0.1	2.9	0

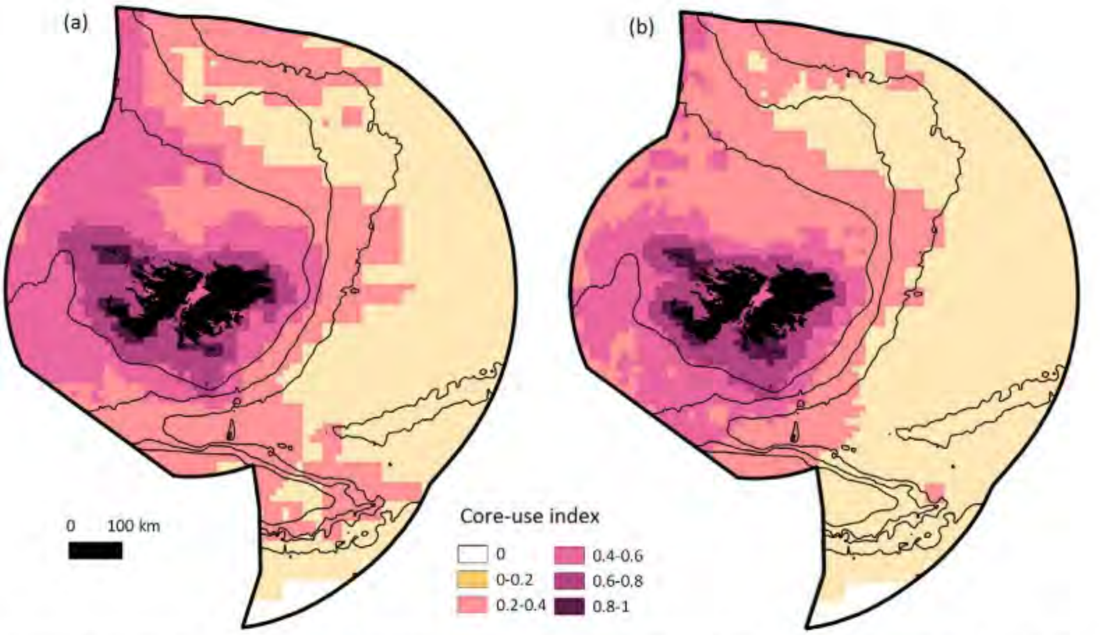


Fig. 3.1: *Early Marine Spatial Planning work by SAERI and published in Augé et al. 2018. Tracking data and at-sea observation data were combined to highlight areas of highest use by seabirds and seals. In the left figure panel, spatial usage is weighted by conservation scores (such as IUCN conservation status). In the right figure panel, spatial usage is weighted by ecological scores (for example, body mass). Our analysis builds upon this work, but focused on seabirds and seals of known provenance and breeding status, data for which was used for a more comprehensive analysis of at-sea spatial usage. Source: Augé et al. 2018.*

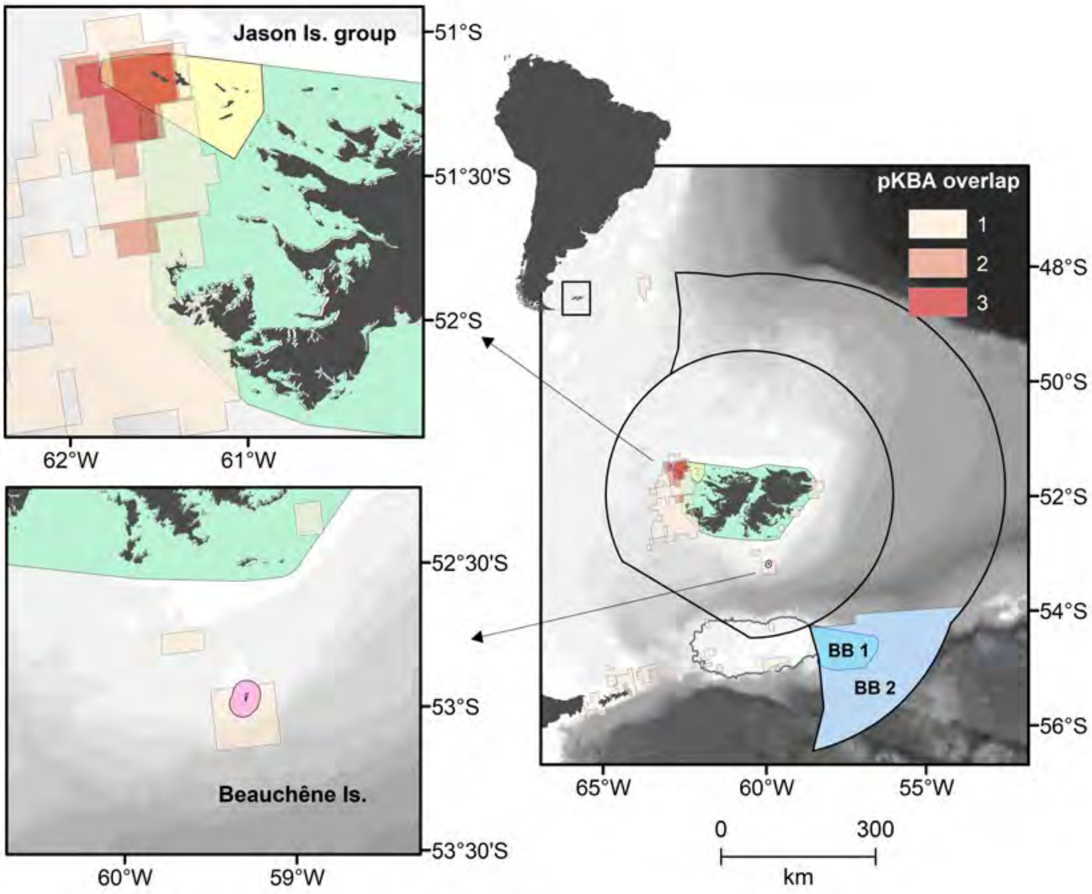


Fig. 3.2: *Proposed network of Marine Managed Areas (MMAs) and potential Key Biodiversity Areas (pKBA) at the Falkland Islands identified using the methods presented in Lascelles et al. 2016, which used First Passage Time (FPT) analysis to define the h value (smoothing parameter used in kernel analysis). Thick black lines are the Falkland Islands Inner and Outer Conservation Zones, within which the Falkland Islands Government manages and regulates commercial activities. Green = Inshore MMA, Yellow = Jason Islands group MMA, Pink = Beauchêne Is. MMA, Blue = Burdwood Bank MMA. BB1 = Burdwood Bank MMA option 1. BB2 = Burdwood Bank MMA option 2. KBAs were identified for black-browed albatross, rockhopper penguins and sooty shearwaters during chick-rearing, and adult female South American fur seals during lactation. See Appendix S1: Fig S1) for individual species KBAs. Source: Baylis et al. 2021*

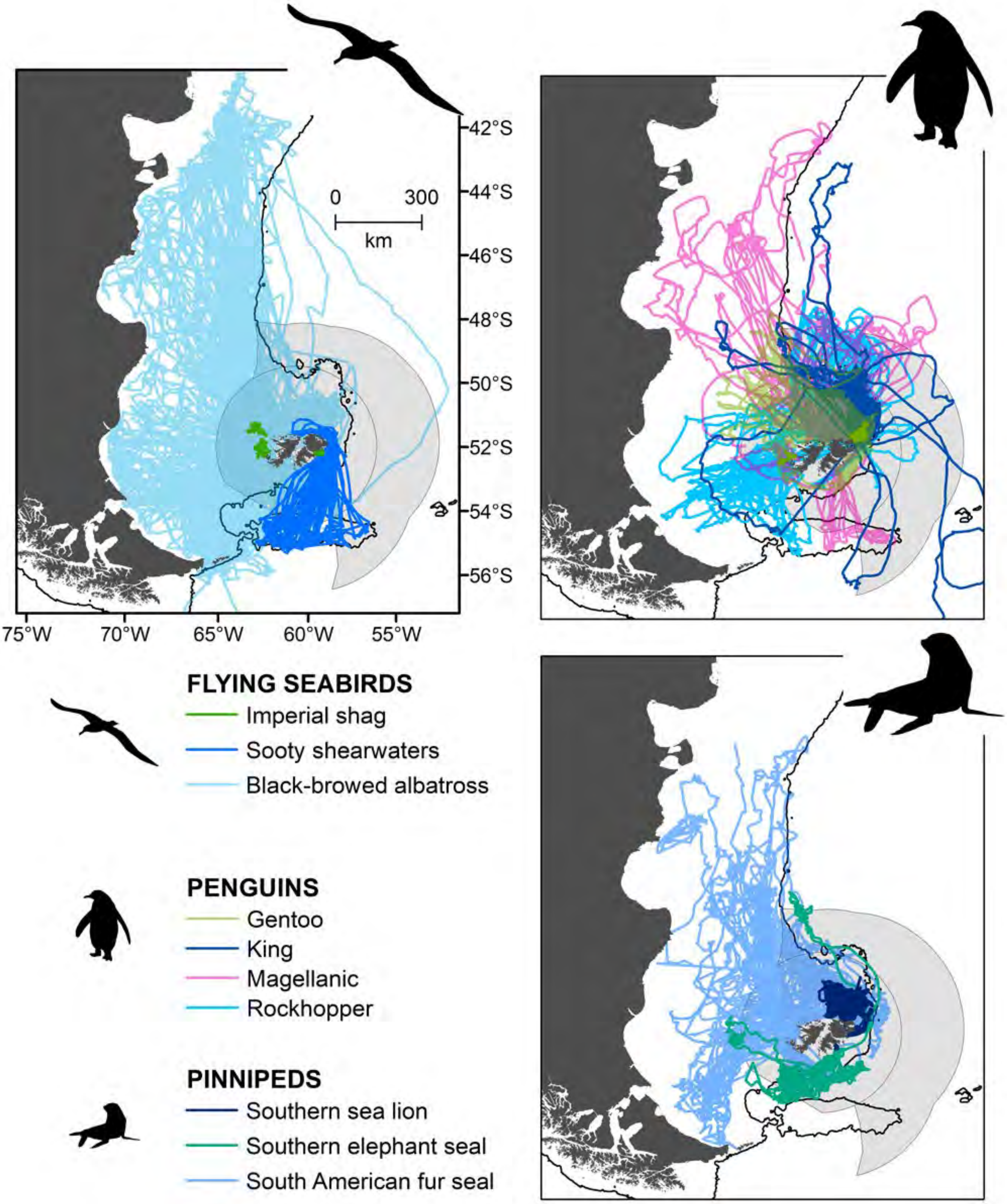


Fig. 3.3: *Summary of biotelemetry and biologging data for the Falkland Islands for the period 2009 - 2020 (see Appendix S1: Table S1 for a detailed breakdown of species and sample size). Black line = 400 m bathymetric contour. Grey shading = Falkland Islands Conservation Zones. Source: Baylis et al. 2021*

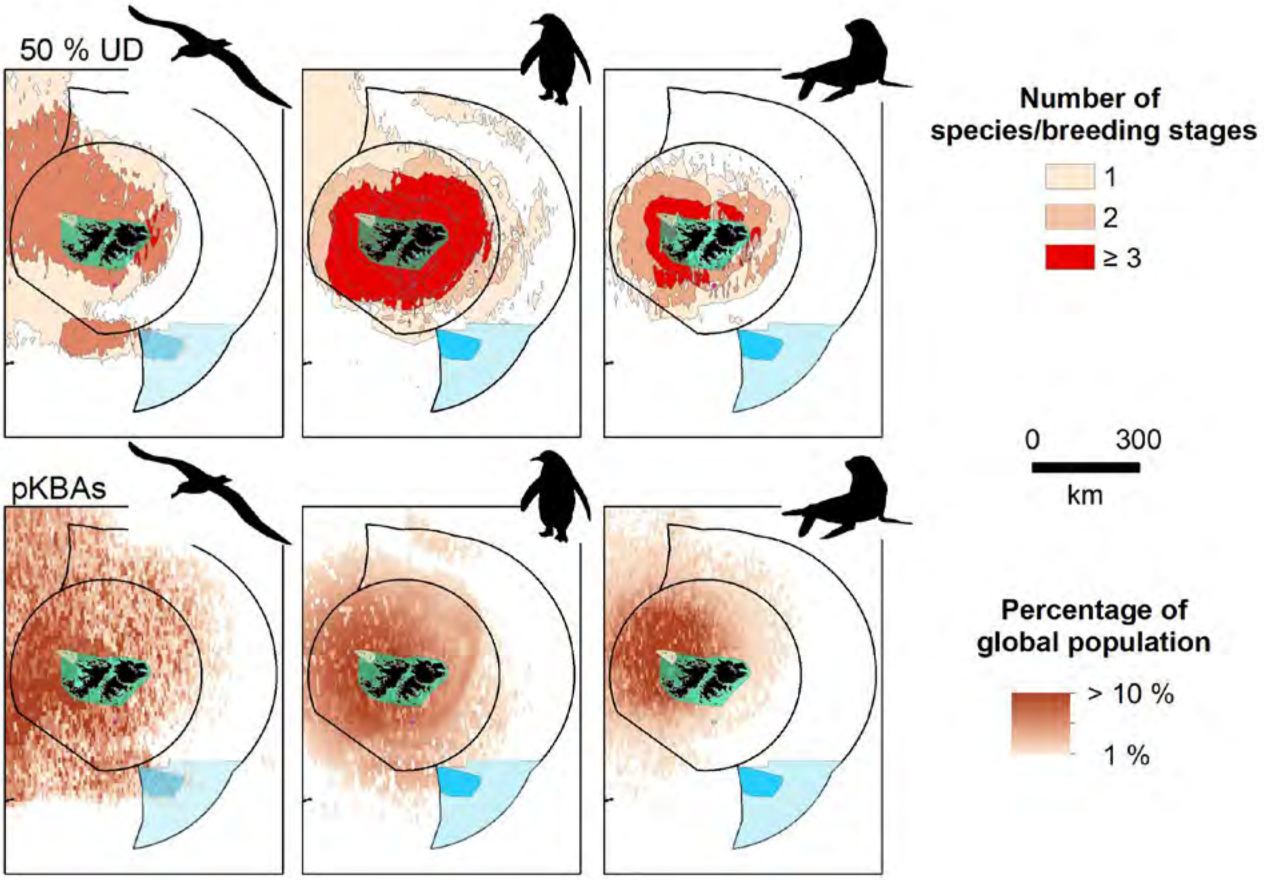


Fig. 3.4: *Predicted distribution (red shading relates to overlap in species/stages) and proposed Marine Managed Areas (MMAs) (see also Table 3.3). Upper panel = 50 % UD (core use areas); lower panels = potential Key Biodiversity Areas (pKBAs; individual data groups overlayed). The lower panels exclude southern elephant seals, Magellanic penguins and king penguins, given these species did not meet IUCN KBA criterion D1a (demographic aggregations ≥ 1 % of the global population size). Green = Inshore MMA, Yellow = Jason Islands group MMA, Blue = Burdwood Bank MMA. Source: Baylis et al. 2021*

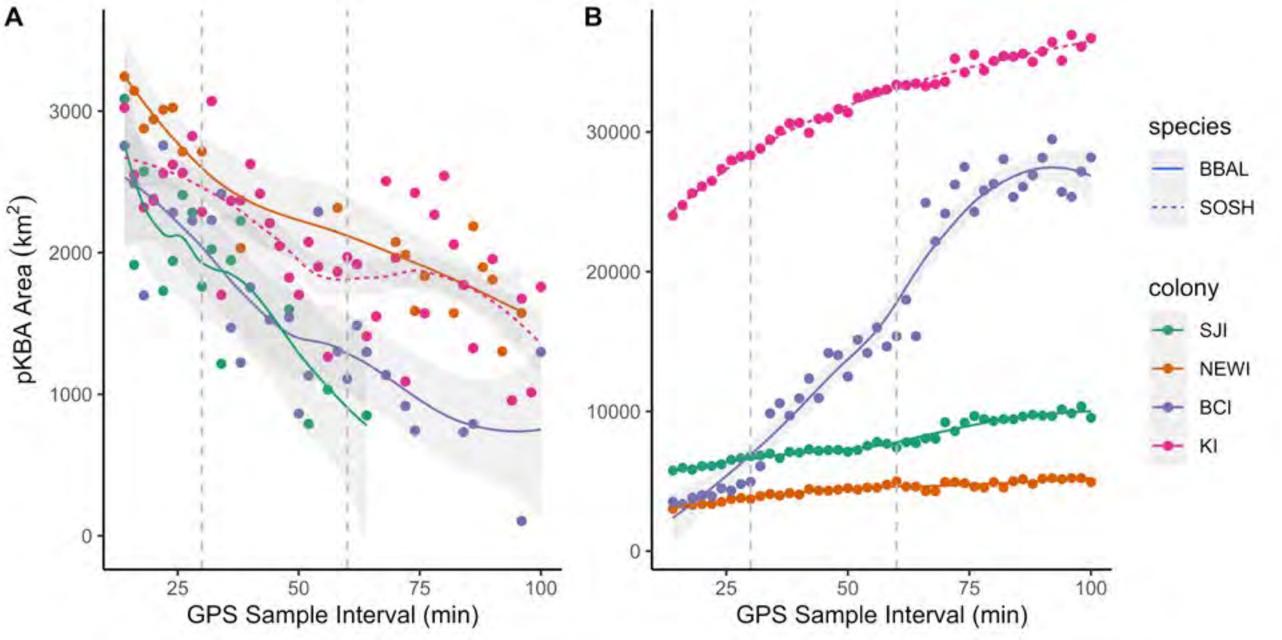


Fig. 3.5: *Effect of interpolated sampling interval upon potential Key Biodiversity Area (KBA) size (km^2) manifested through effects on the estimated kernel smoothing parameter (h) using GPS data for flying seabirds – note change in scale on x-axis between figure panel A and B. When using First Passage Time to define the h value (A), KBA size was negatively correlated with the sampling interval. In contrast, when using a h value based on variance in foraging trip latitude and longitude (B), KBA size was positively correlated with the sampling interval. BBAL = black-browed albatross, SOSH = sooty shearwater, SJI = Steeple Jason Island, NEWI = New Island, BCI = Beauchêne Island, KI = Kidney Island. Dashed vertical lines are 30 minute and 1-hour intervals, which are commonly selected sampling intervals. Source: Baylis et al. 2021*

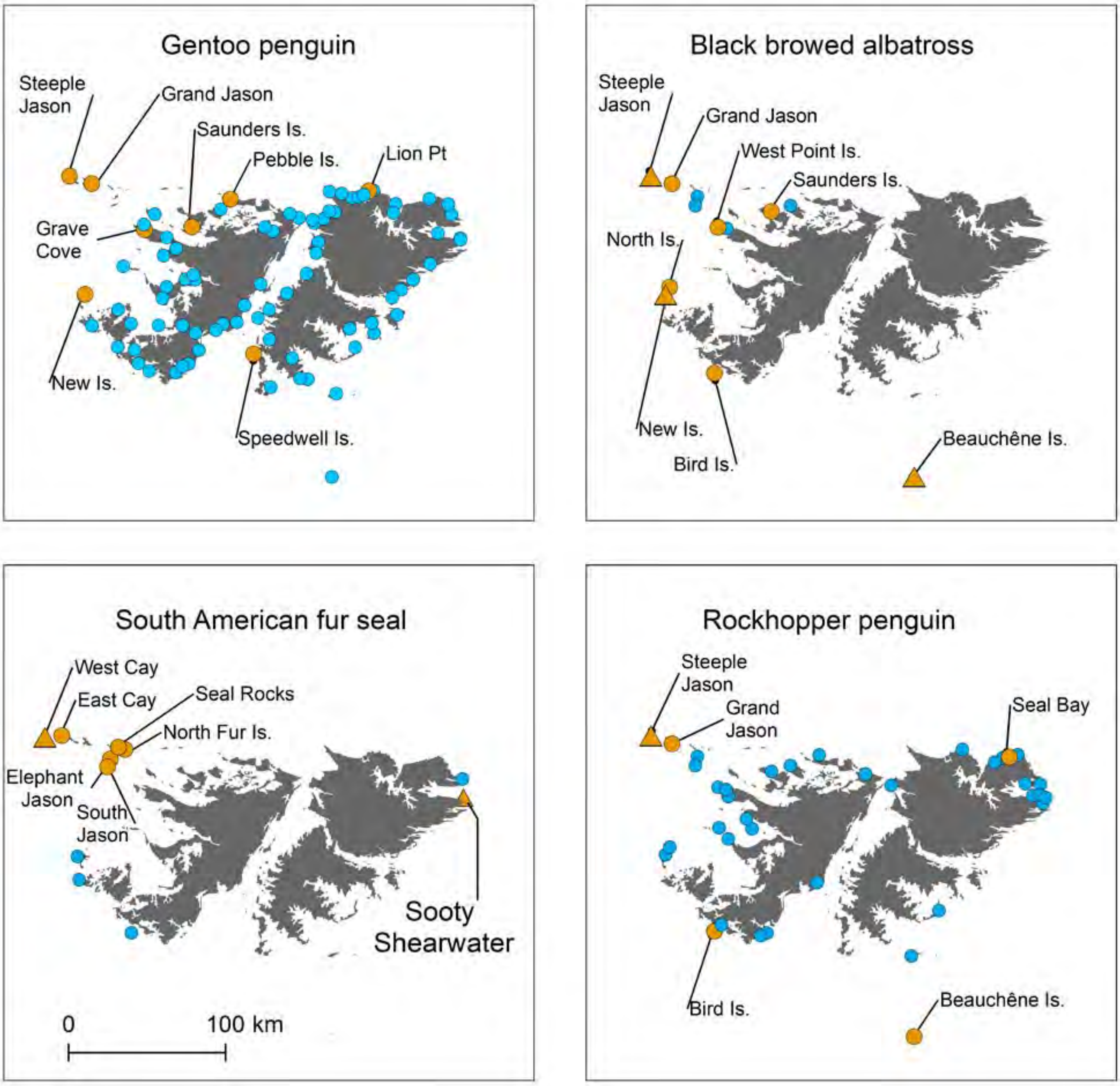


Fig. 3.6: *Breeding locations for key species in the analysis. Blue dots represent breeding colonies. Orange dots represent breeding colonies that have ≥ 1 % of the global population. Orange triangles represent sites where sufficient data existed to undertake KBA analysis. Source: Baylis et al. 2021*

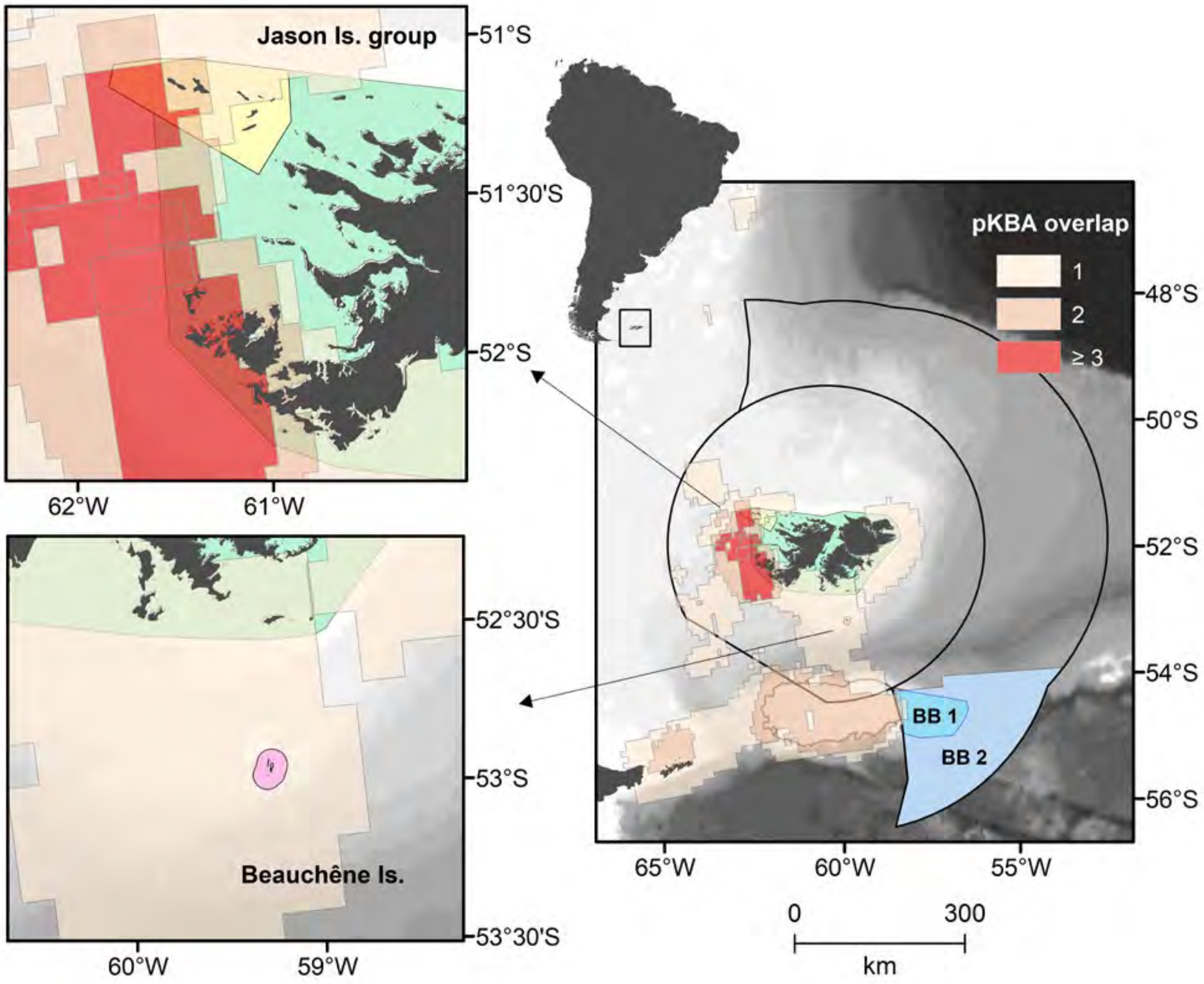


Fig. 3.7: As in Fig 3.1, however potential Key Biodiversity Areas (pKBA) were calculated using a h value based on variance in foraging trip latitude and longitude. See Appendix S1: Fig S1 for individual species KBAs. Source: Baylis et al. 2021

3.2 CETACEANS: OVERVIEW OF RECENT CETACEAN SURVEYS AND RELEVANCE TO PROPOSED MMAs

SUMMARY

- We collated aerial, boat and land based cetacean survey data. Recent surveys were primarily conducted within the proposed Falkland Islands MMAs. Therefore, the majority of cetacean sightings, including 99 % of confirmed sei whale sightings, were within the boundaries of the proposed MMAs.
- The most notable exception was sightings of baleen whales to the north of the Falkland Islands, outside of the proposed inshore MMA.
- Combined, data from recent surveys highlights the importance of the proposed inshore MMA to cetaceans.
- Given there is limited survey data outside of the proposed MMAs, predictive models are a useful tool to explore probable distribution of cetaceans over larger areas. The predictive models for sei whales and Commerson's dolphins highlight that the probability of occurrence typically declines with distance away from the Falkland Islands coastline. In contrast to Commerson's dolphins and sei whales, the distribution of Peale's dolphins were relatively uniform around the Falkland Islands coastline, with the largest group sizes recorded in the south west of the Falkland Islands.
- Predictive models also revealed 'hotspots' of predicted occurrence – where there was a higher probability of finding high numbers of cetaceans. For both Commerson's dolphins and sei whales, the majority of the 'hotspots' fall within the proposed inshore MMA, which supports the importance of the inshore MMA for cetaceans.
- With regard to the designated sei whale KBA, the proposed MMAs are ecologically relevant and will enable the persistence of the biodiversity elements for which the sei whale KBA was designated. That is, the proposed MMAs offer enhanced protection for the sei whale KBA.
- Ideally, future cetacean surveys could venture beyond the proposed MMA boundaries to understand cetacean abundance outside of proposed MMAs.

Image: Peale's dolphin. Credit: SAERI.

INTRODUCTION

Some 25 cetacean species have been recorded in the Falkland Islands (Table 3.4) (Otley 2012). Of these, about eight species regularly present, including two year-round resident species, Commerson's dolphin (*Cephalorhynchus commersonii*) and Peale's dolphins (*Lagenorhynchus australis*) and seasonal visitors such as migratory baleen whales (*Mysticeti*) including sei whales (*Balaenoptera borealis*), fin whales (*B. physalus*), minke whales (*B. acutorostrata/B. bonarensis*), humpback whales (*Megaptera novaeangliae*) and southern right whales (*Eubalaena australis*) (Table 3.4). Prior to 2016, limited cetacean survey data existed, and knowledge of cetacean distribution was primarily based on opportunistic surveys, and stranding records (White et al. 2002, Otley 2012). Beginning in 2016, several multi-year projects have quantified cetacean abundance and distribution around the Falkland Islands through systematic surveys, with a focus on Commerson's dolphins, Peale's dolphins and sei whales (Table 3.5, Fig. 3.8). There have also been recent opportunistic cetacean surveys (e.g., those carried out by SAERI on the James Clarke Ross in 2019 and 2020). However, this chapter specifically focusses on systematic survey efforts for Commerson's dolphins, Peale's dolphins and sei whales and provides a qualitative review of these surveys.

In brief, Peale's dolphins are distributed in the coastal waters of southern South America and the Falkland Islands, including the Drake Passage. Recent genetic analysis of Peale's dolphins at the Falkland Islands indicates significant genetic differences between the East Falkland and West Falkland populations of Peale's dolphins, and between mainland South America, suggesting limited connectivity between populations (Costa et al. 2018). Commerson's dolphins are a nearshore species found in southern South America and a separate population also found in the Kerguelen Islands. The Falkland Islands Commerson's dolphins are likely to be a genetically distinct subpopulation from those found in South America (Costa et al. 2018). Finally, sei whales are typically found in deep, offshore waters, and therefore their occurrence in nearshore Falkland Islands waters is unique (Weir 2021). The Falkland Islands are an important feeding and resting area for sei whales during their seasonal migration (Weir 2021).

Overview of survey methods and results, and relevance to proposed MMAs

SAERI undertook several cetacean surveys between 2016 and 2018 as part of the 'Dolphins of the Kelp Project' (Costa and Cazzola 2018) (please find a full list of project publications **here**). This included numerous boat-based surveys and one aerial survey, given evidence suggests dolphins in particular are attracted to vessels, which in-turn can bias survey results (Table 3.5). The aerial survey was carried out between 18th of March to the 8th of May 2017 and included 217 transects up to 6 km apart, with an overall transect length of 4,317 km (Fig 3.9). Observers searched for cetaceans 90 degrees port or starboard of the transect line and the location of a sighting recorded (Costa and Garcia 2017). A total of 454 cetacean were recorded including 238 Commerson's dolphin, 60 Peale's dolphin, 74 sei whales, 12 fin whales, 2 blue and minke whales and 1 southern right whale. The remaining 65 sightings were unidentified baleen whales. The aerial survey covered the extent of the Falklands while the boat-based surveys were constrained to specific areas.

Boat based surveys included 5 focal studies (surveys where pre-established transects were typically not followed) were carried out from summer 2016 to winter 2018. The focal study was carried out in three areas (1 - Port Stanley, Port William and Berkeley Sound; 2 - Choiseul Sound; 3 - Port Howard and Many Branch) using photo-identification and passive acoustic monitoring methods (Fig S2). Tissue sampling was also undertaken to determine genetic diversity and local population structure (Costa and Cazzola 2018). Observations were carried out by two observers and dolphin group size and age composition were estimated, and photographs taken for photo-identification (for the "capture" and "recapture" of individuals without physical handling, allowing for information such as population abundance and individual survival). In total, 476 dolphins were recorded over 3,692 km of survey effort. A final survey was carried out from the 21st of February to the 1st of March 2017 (Costa and Cazzola 2017). The survey was again a focal study and covered 590 km (Fig S3). A total of 337 sightings and five cetacean species were recorded, including 149 Commerson's dolphins, 106 Peale's dolphins and 48 sei whales. The Photo-ID study indicated Commerson's dolphins in the Port Howard survey area had higher site fidelity, when compared to other survey areas, where the same individuals were recorded in both the Port Stanley survey area and Choiseul Sound (Fig S2). For Peale's dolphins, no individuals were recorded in more than one survey area (Costa and Cazzola, 2018).

Combined, the SAERI aerial and boat-based surveys amounted to 1,267 sightings of cetaceans and covered some 8,599 km of transects. These surveys enabled estimates of cetacean abundance which included 5,789 (CV = 0.18) Commerson's dolphins, 1,896 (CV = 0.33) Peale's dolphins, 341 (CV = 0.21) sei whales, although subsequent and dedicated sei whale surveys estimated 716 sei whales (CV =0.22) (Weir 2021). Of the 1,267 cetacean sightings, 98 % were within the proposed MMAs (Fig. 3.8, Fig. 3.9, Fig. 3.10). However, both aerial and boat-based cetacean surveys rarely ventured outside the boundaries of the proposed MMAs, presumably due to logistical constraints and because encounter rates were anticipated to decline with distance away from the Falkland Islands coastline (Fig. 3.8). This assumption is, at least to some degree, supported by opportunistic surveys undertaken in the 1990s that show Peale's dolphins, Commerson's dolphins, and sei whale sightings were typically on the Patagonian Shelf (Fig. 3.11). The more recent survey work by SAERI revealed that Commerson's dolphins were often encountered in near shore, relatively shallow and sheltered waters, including harbours, bays and sounds (Figure 3.9). Peale's dolphins were found in both offshore and near shore waters, while Baleen whales were distributed widely around the Falkland Islands, with the exception of the south west of the Falkland Islands (Fig 3.9, Fig 3.10) (Costa and Garcia 2017).

Several sei whale surveys between 2017 and 2019 were undertaken by Falklands Conservation within Berkley Sound, Falkland Sound and West Falkland (Fig 3.12) (Baines and Weir 2020). In total, 7,460 km of surveys were undertaken and 2,530 cetacean sightings recorded (Baines and Weir 2020). The areas surveyed were predominantly within the boundaries of the proposed MMAs (Fig 3.12). Accordingly, the majority of sei whale sightings are within the proposed MMAs, the exception being sightings to the north of Falklands Sound (Fig 3.8 and Fig 3.12). There was significant spatial clustering of sei whales in Queen Charlotte Bay, although this may have been influenced by survey effort (Fig 3.12). That sei whales were frequently encounter in nearshore coastal waters is perhaps unsurprising, because sei whales migrate to the Falkland Islands to feed on seasonally abundant prey including lobster krill (*Munida gregaria*) and amphipods, which are found in high abundance in nearshore waters (Clausen et al. 2005, Baines and Weir 2020).

The limited survey data both within and outside of the proposed MMAs, means that predictive models are a useful tool to explore probable distribution over larger areas. Models that predicted the abundance of Commerson's dolphins indicated higher abundance in the Falkland Sound, and the northern coastline of the Falkland Islands – although these models provided predictions that were largely within the proposed inshore MMA (Franchini et al. 2020) (Fig 3.13, Fig S4). Similarly, sei Whale abundance was also predicted to be highest in the Falkland Sound and over much of the northern coastline of the Falkland Islands, and Queen Charlotte Bay, West Falklands (Fig 3.14) (Baines and Weir 2020), which is further supported by hotspots derived from 350 opportunistic observations collated between 2010 and 2015 (Frans and Augé 2016) (Fig 3.15). In contrast to sei whales and Peale's dolphins, the distribution of Commerson's dolphins were relatively uniform around the Falkland Islands coastline, with the largest group sizes recorded in the South West of the Falkland Islands (Fig 3.13). Predicted abundance appears to increase with distance from the Falkland Islands coastline (Fig 3.13).

In 2021 a sei whale Key Biodiversity Area (KBA) was declared, which highlights the importance of Falkland Islands waters to seasonally migrating sei whales (Fig 3.16) (Weir 2021). The sei whale KBA boundary loosely follows the 100 m bathymetric contour, which was chosen because of ecological relevance and ease of management (Weir 2021). IUCN guidelines highlight that the boundaries of KBAs should, wherever possible, use existing protected area boundaries. Specifically, conservation efforts are strengthened using existing protected area boundaries because, unlike KBAs, protected areas "*often have national recognition, active conservation and monitoring initiatives, and may be linked to legislative and policy processes*" (IUCN 2019). Therefore, ideally the Falkland Islands sei whale KBA boundary could have taken into consideration the proposed Falkland Islands MMA boundaries, given the proposed MMAs will be underpinned by legislation and policy, and presumably supported by management and monitoring plans. The proposed Falkland Islands MMAs are also near pristine marine wilderness areas, which are closed to fishing or subject to low fishing impact and are important sites for a diverse range of taxa and habitats. Although there is considerable local interest in KBAs, it could be difficult to base MMAs on the designated KBA boundaries, because almost all of our surrounding ocean is likely to be a KBA (over 70 % of our ocean, based on seabirds and seals alone), which makes systematic conservation planning on the basis of KBAs, challenging. The sei whale KBA does however, further emphasize the importance of our inshore waters. Over 70% of the sei whale KBA overlaps with the proposed MMAs (Fig 3.16), which strengthens justification for designating the proposed MMAs and establishing a legal framework for protection. The proposed MMAs boundaries are also ecologically relevant to sei whales (encompass 99% of confirmed sightings and the majority of predicted hot spots) and will enable the persistence of the biodiversity elements for which the sei whale KBA was designated (Fig 3.8, Fig 3.16). Ultimately, the proposed MMAs should offer enhanced protection for the designated sei whale KBA.

In conclusion, almost all cetacean sightings from recent surveys are within the proposed MMAs, with few exceptions. However, both aerial and boat-based cetacean surveys rarely ventured outside the boundaries of the proposed MMAs. Predictive models allow us to infer the probable occurrence of cetaceans over larger areas (although it is important to recognize and understand limitations with predictive models, especially given the lack of off-shore data). The predictive models for sei whales and Peale's dolphins highlight that the probability of occurrence typically declines with distance away from the Falkland Islands coastline. Most of the predicted hotspots of Peale's dolphins and sei whales fall within the proposed inshore MMA. In contrast to sei whales and Peale's dolphins, the distribution of Commerson's dolphins were relatively uniform around the Falkland Islands coastline, with predicted abundance higher with increasing distance from the Falkland Islands coastline. Ideally, future cetacean surveys could venture beyond the proposed MMA boundaries to better quantify cetacean abundance outside of the proposed MMAs.

Table 3.4. List of cetaceans found in the Falkland Islands. Source: (Costa et al. 2018)

Species	IUCN Conservation status	Occurrence in the Falkland Islands	Typical habitat
Peale's dolphins (Lagenorhynchus australis)	LC	Resident – present year-round	Nearshore, Pelagic Shelf (<200m) and small offshore islands
Commerson's dolphins (Cephalorhynchus commersonii)	LC	Resident – present year-round	Estuarine and Near shore coastal
sei whales (Balaenoptera borealis)	EN (population increasing)	Regular and most numerous – typically present December to May.	Nearshore coastal, Pelagic Shelf (<200m) and deep sea
Southern Right whales (Eubalaena australis)	LC	Regular – typically present May to August.	Nearshore coastal and Pelagic Shelf (<200m)
Minke whale		Regular - Both the Antarctic minke whale (NT) and the dwarf subspecies of the common minke whale (LC) potentially occur in the Falkland Islands	Nearshore coastal and Pelagic Shelf (<200m)
Fin whale (Balaenoptera physalus)	VU (population increasing)	Regular– typically during summer months	Nearshore coastal, Pelagic Shelf (<200m) and deep sea
Sperm whale	VU	**Regular** - Year-round	Shelf break or slope
humpback whale (Megaptera novaeangliae)	LC (population increasing)	Regular - anecdotally, the number of humpback whales that frequent Falkland Islands waters are increasing	Nearshore coastal and Pelagic Shelf (<200m)
Killer whales			
(Orcinus orca)	DD	Regular - Sea Lion Island has a small pod is regularly observed from September to March.	Nearshore coastal and Pelagic Shelf (<200m) an shelf break or slope
Blue whale	EN	Rare	Pelagic Shelf (<200m) and deep sea
Pygmy right whale	DD	Presently unknown	Deep sea
Andrews' beaked whale	DD	Presently unknown	Shelf break or slope
Gray's beaked whale	LC	Presently unknown	Shelf break or slope
Hector's beaked whale	DD	Presently unknown	Shelf break or slope
Strap-toothed beaked whale	LC	Presently unknown	Shelf break or slope
Cuvier's beaked whale	LC	Presently unknown	Shelf break or slope

Arnoux's beaked whale	LC		Shelf break or slope
Southern bottlenose whale	LC	Regular	Shelf break or slope
Long-finned pilot whale	LC	**Regular** - Year-round	Shelf break or slope
False killer whale	NT	Presently unknown	Pelagic shelf
Common bottlenose dolphins	LC	Presently unknown	Nearshore, Pelagic Shelf (<200m) and small offshore islands
Hourglass dolphin	LC	**Regular** - Spring-Summer	Deep sea
Dusky dolphin	LC	Rare	Deep sea
Southern right whale dolphin	LC	Rare	Deep sea
Spectacled porpoise	LC	Rare	Deep sea

Table 3.5. An overview of cetacean surveys in the Falkland Islands.

Project title	Species	Data range (year)	Survey type	Reference
The distribution of seabirds and marine mammals in the Falkland Islands waters	Sei whale, Commerson's and Peale's dolphins	1998-2001	At-sea survey including vessels of opportunity – archipelago wide	White et al. 2002
Developing a site-based conservation approach for sei whales, Balaenoptera borealis, at Berkeley Sound	Sei whale	2016-2017	Shore, aerial and boat based surveys – Berkley Sound	Weir et al. 2021
Dolphins of the kelp (DOKE)	Commerson's and Peale's dolphins	2017-2018	Boat based survey	Costa and Cazzola 2018
Dolphins of the kelp (DOKE)	Sei whale, Commerson's and Peale's dolphins	2017	Archipelago wide aerial survey	Costa and Garcia 2017
Conserving Falklands' whale populations: addressing data deficiencies for informed management.	Sei whale	2018-2019	Boat based survey – archipelago wide, but with greatest effort on West Falklands.	Weir et al. 2021

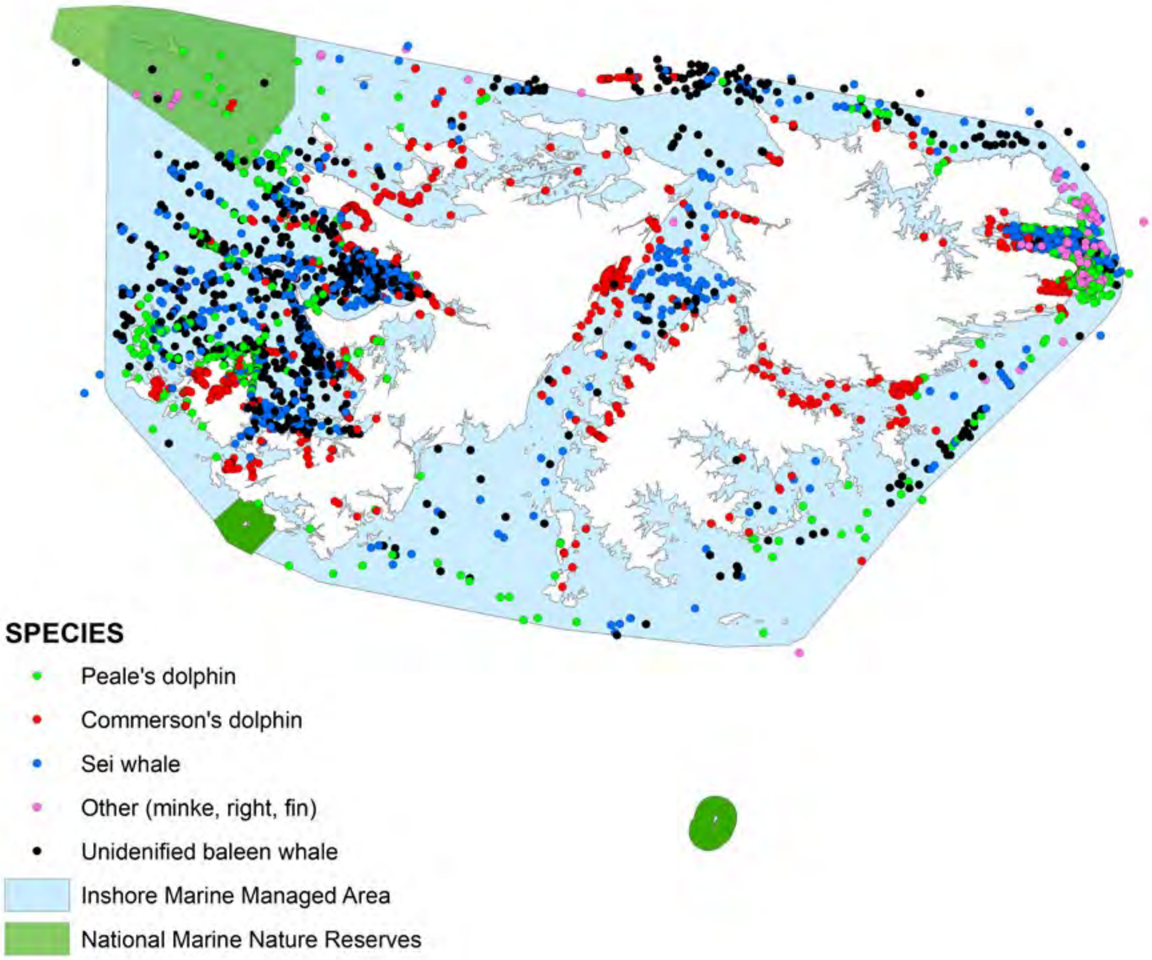


Fig. 3.8: *Recent cetacean survey efforts by SAERI and Falklands Conservation between 2016-2018 have rarely ventured outside the boundaries of the proposed Marine Managed Areas (MMA). Accordingly, the majority of cetacean sighting records are within the proposed MMAs. Blue shading = proposed Inshore MMA, Green shading = proposed National Marine Nature Reserves. Data source: (Costa and Garcia 2017, Costa and Cazzola 2018, Baines and Weir 2020).*

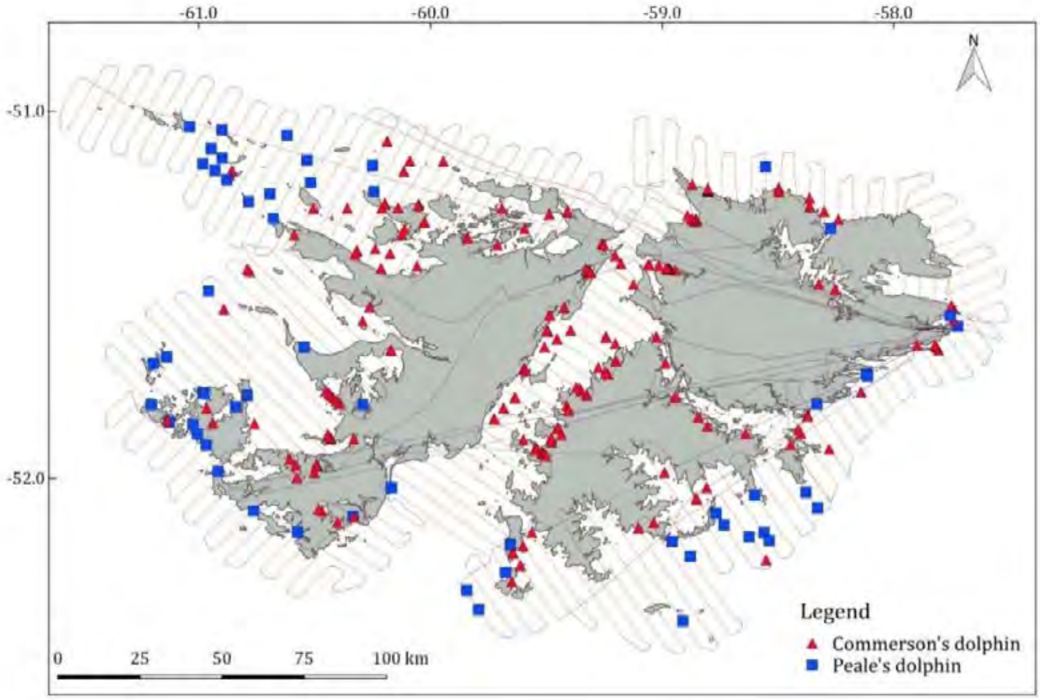


Fig. 3.9: *Distribution of Commerson's dolphins and Peale's dolphins during the SAERI aerial survey in 2018. Source: (Costa and Garcia 2017).*

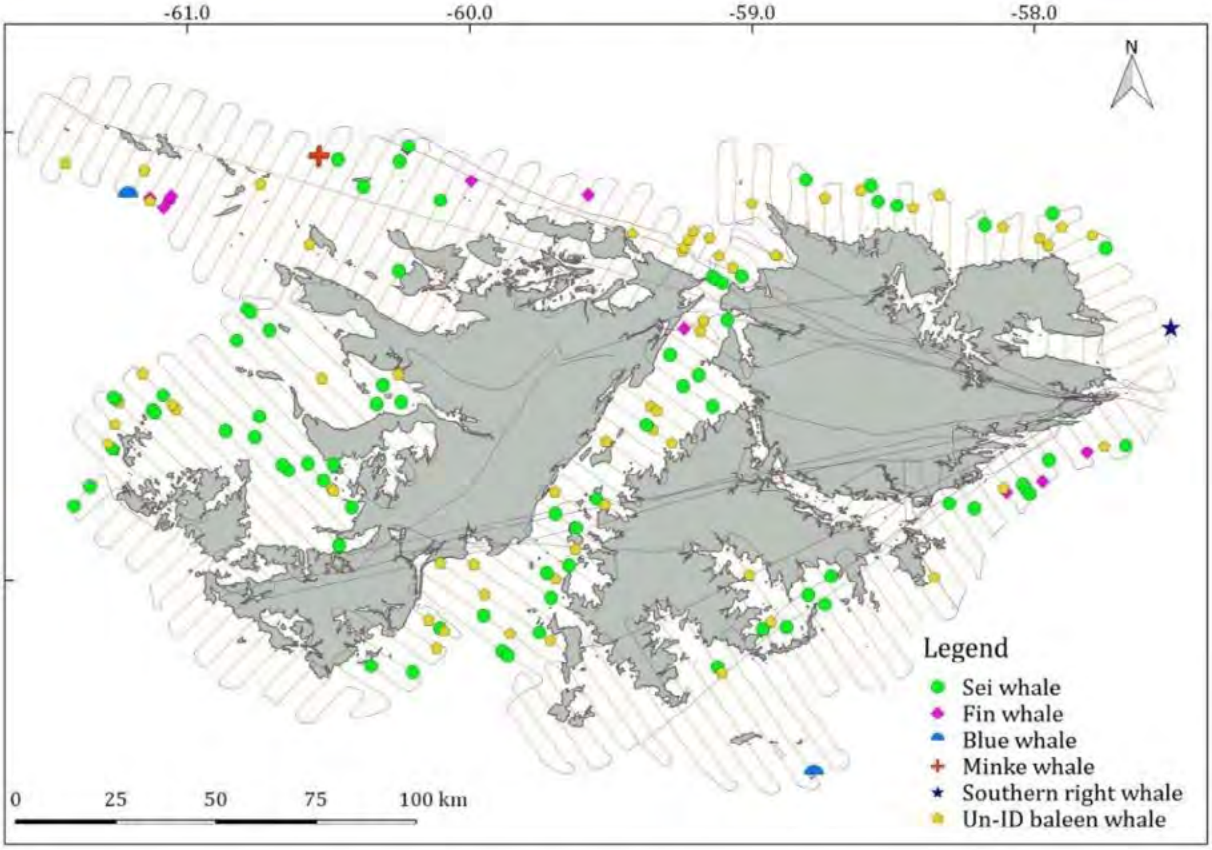


Fig. 3.10: *Distribution of baleen whales recorded during the SAERI aerial survey in 2018. Source: (Costa and Garcia 2017).*

Image: Commerson's dolphin. Credit: SAERI.

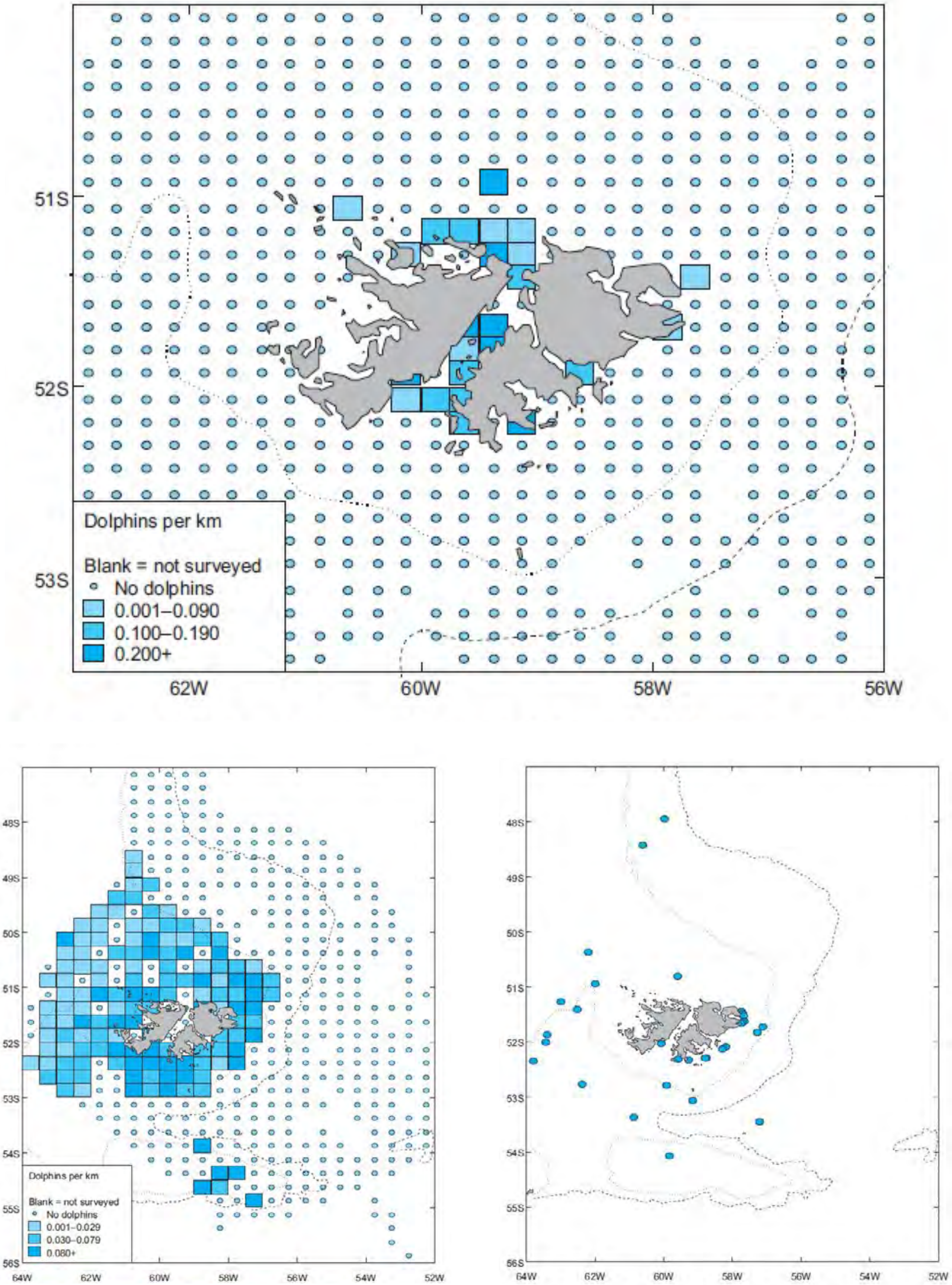


Fig. 3.11: *At-sea survey data from White et al. 1993. Although the data is outdated, it is useful because it provides sighting data over a larger area than contemporary studies. Commerson's dolphins (upper panel) are found within nearshore waters, Peale's dolphins (lower left panel) and sei whales (right panel) have a wider distribution around the Falkland Islands. Source: (White et al. 1993).*

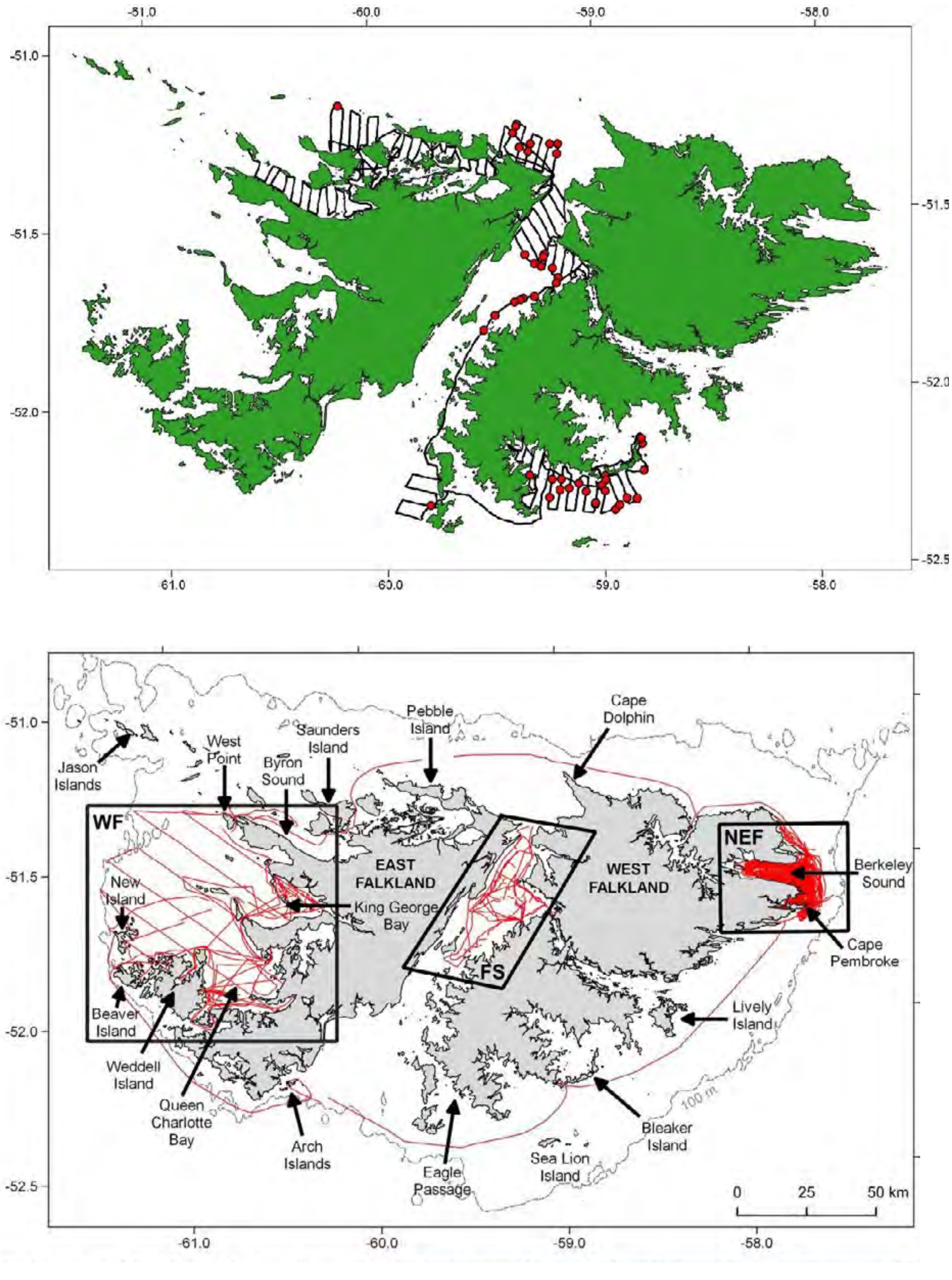


Fig. 3.12: *Recent sei whale surveys conducted by Falklands Conservation. The upper panel was an inshore cetacean survey conducted in 2014. The lower panel was boat, aerial and shore based sei whale surveys between 2017-2019. The majority of survey effort was within the boundaries of the proposed inshore MMA (see fig 3.16). Source: (Thomsen and Munro 2014, Baines and Weir 2020).*

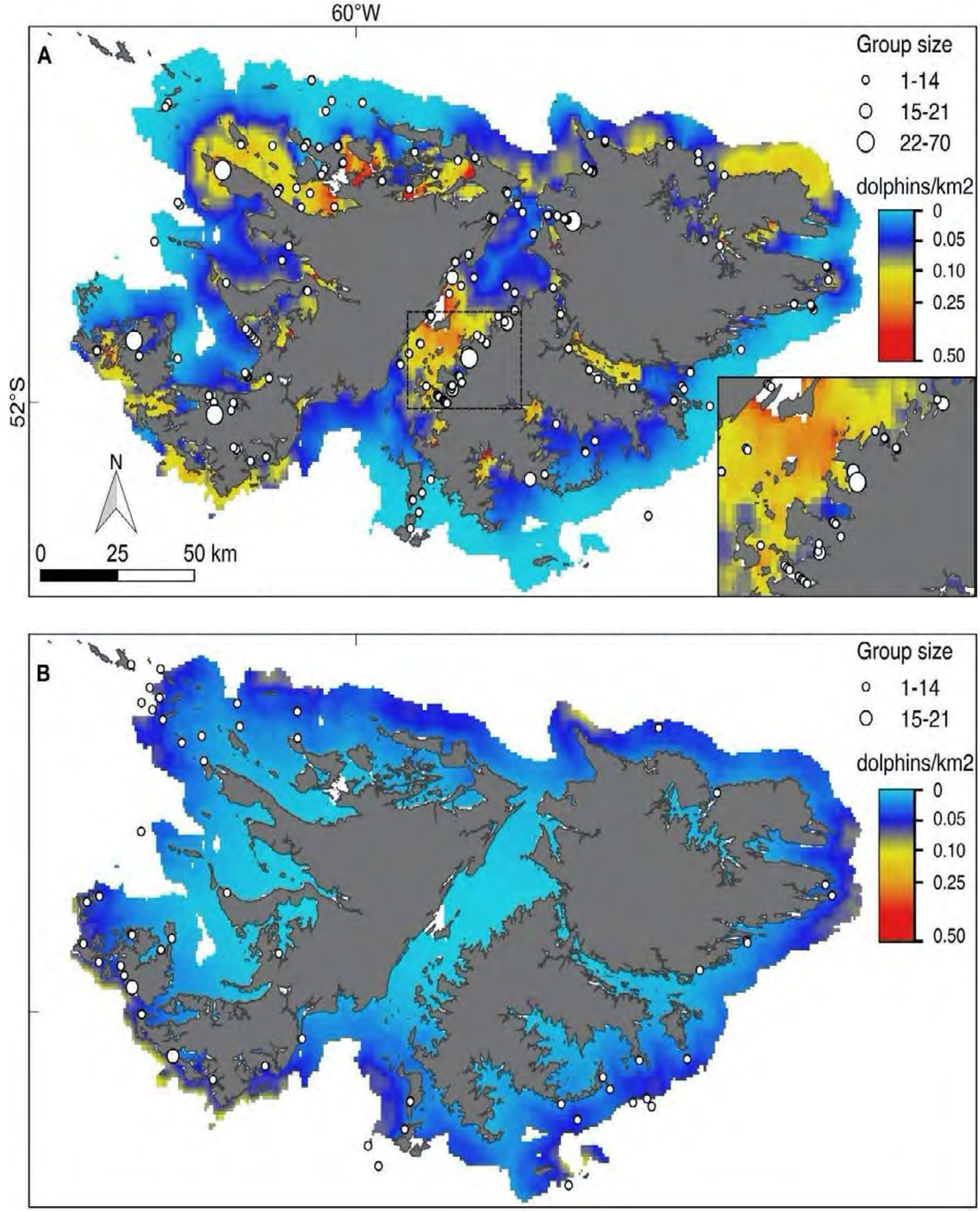


Fig. 3.13: *Predicted abundance of Commerson's dolphins (upper panel) and Peale's dolphins (lower panel), with survey data (presence data) represented by circles. Source: (Franchini et al. 2019).*

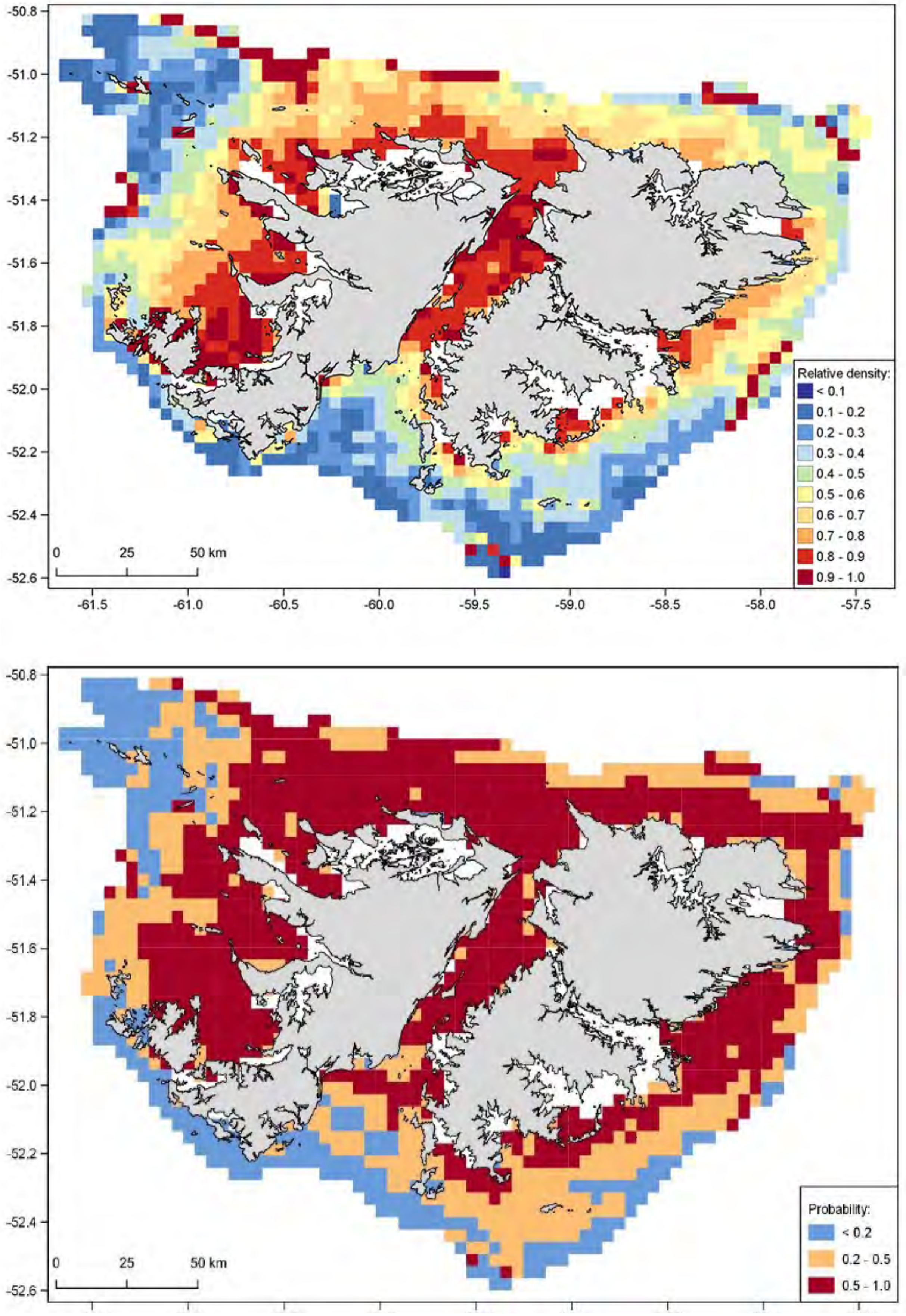


Fig. 3.14: *Predictive models for sei whales, depicting the probability of occurrence. The majority of 'hotspots' – or areas of the highest probability of occurrence – fall within proposed inshore MMA (Fig 3.16) – with notable exceptions to the north of the Falkland Islands. Upper panel is modelled using a MaxEnt model (Maximum Entropy). Lower panel is the combined Generalized Additive Model (GAM) and a MaxEnt model. Note the difference in scale between the upper and lower panel. Source: (Baines and Weir 2020 & Weir et al. 2021).*

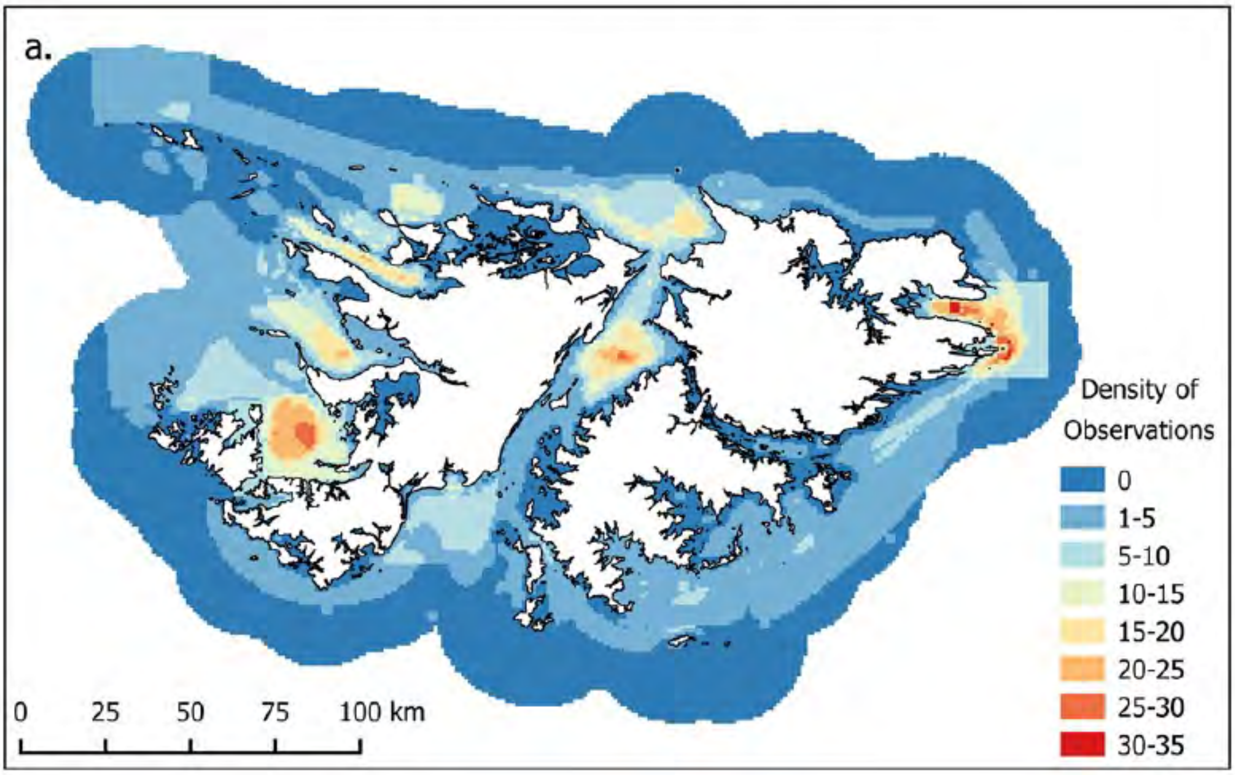


Fig. 3.15: *Baleen whale hotspots derived from 350 opportunistic observations collated between 2010 and 2015. Source: (Frans and Augé 2016).*

Image: Peale's dolphin. Credit: SAERI.

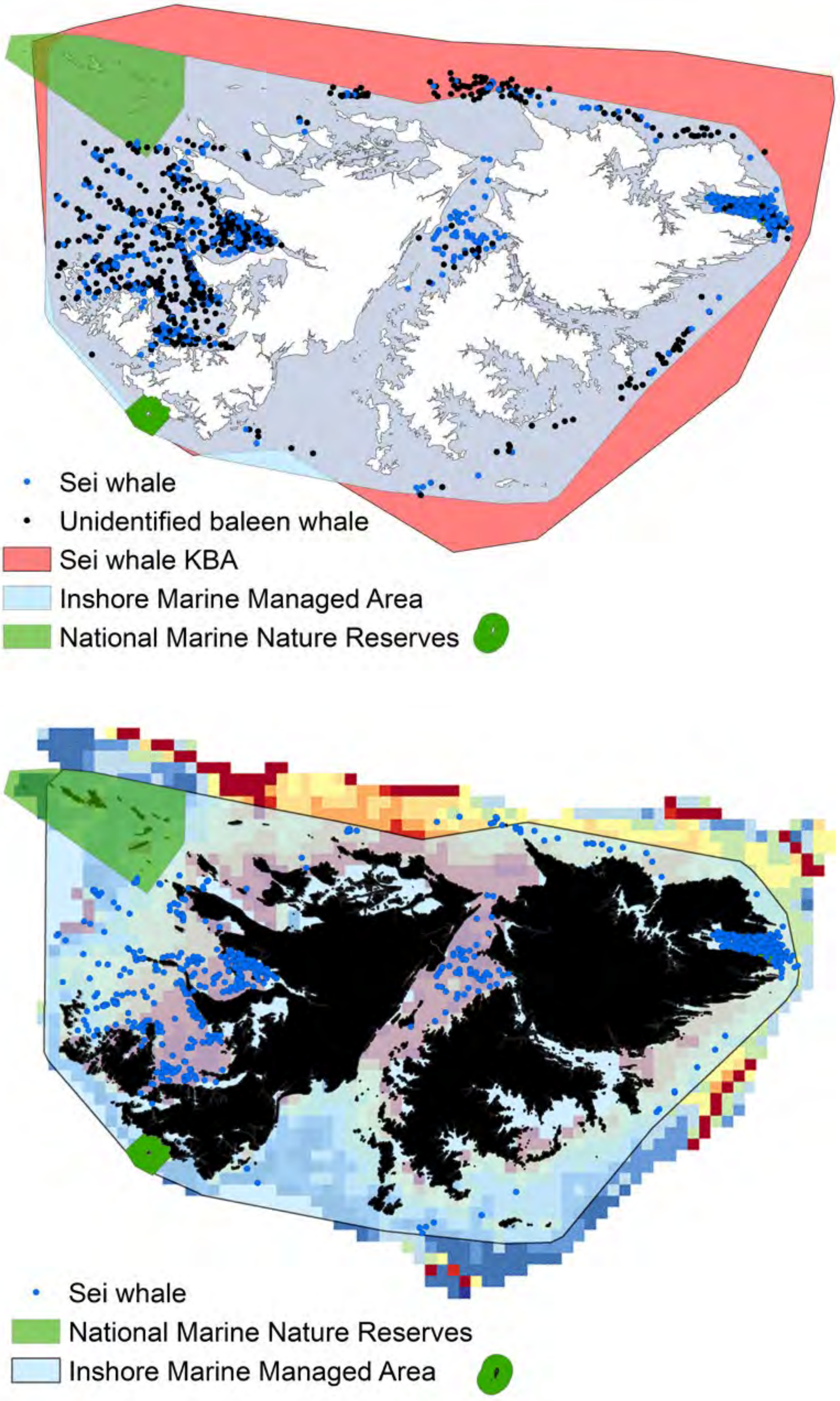


Fig. 3.16: *The proposed Falkland Islands Marine Managed Areas (MMAs) were identified in 2018. The MMAs are near pristine marine wilderness areas, which are closed to fishing or subject to low fishing impact and are important sites for a diverse range of taxa and habitats. In 2021, a Key Biodiversity Area (KBA) for sei whales was identified, which loosely follows the 100 m bathymetric contour around the Falkland Islands (upper panel). Over 70 % of the sei whale KBA is captured by the proposed MMAs (which include Inshore MMA and National Marine Nature Reserves at the Jason Islands, Bird Island, Kidney and Cochon Island and Beauchêne Island). The proposed MMAs encompass 99 % of confirmed sei whale sightings (649 of 656 observations: upper panel), and the majority of the predicted sei whale hotspots (lower panel, darker colours related to a higher probability of sei whale occurrence) (see also Fig 3.14). Combined, this data emphasizes the importance of the inshore MMA to sei whales. Also shown are unidentified baleen whales (upper panel, black dots). The proposed MMAs offer enhanced protection for the sei whale KBA. Data source: (Baines and Weir 2020).*

APPENDIX S1

Table S1. Biotelemetry and biologging data collated for ten central-place colonial marine predators breeding at the Falkland Islands. Data include 707 unique individuals and 1,934 foraging trips. aTotal number of rockhopper penguins tracked was 151, but some birds were tracked over both incubation and chick rearing periods. bTotal number of black-browed albatross tracked was 303, but some birds were tracked over both incubation and chick rearing periods. cTotal of 17 female South American fur seals were tracked.

Species	Season	Stage	Individuals tracked	Foraging trips	Trip distance (km) max [mean ± SD]	Data Source
Flying seabirds						
Black-browed albatross[b]	Summer (Steeple Jason)	Incubation	43	47	1239 [538 ± 378]	(Granadeiro et al. 2011, Catry et al. 2013, Campioni et al. 2017)
Thalassarche melanophris	Summer (Steeple Jason)	Chick rearing	53	115	514 [147 ± 141]	
	Summer (New Island)	Incubation	35	43	1196 [386 ± 334]	
	Summer (New Island)	Chick rearing	155	393	667 [191 ± 151]	
	Summer (Beauchêne)	Incubation	29	101	1319 [681 ± 499]	
	Summer (Beauchêne)	Chick rearing	4	12	551 [282 ± 128]	
Sooty shearwater *Ardenna grisea*	Summer	Incubation	20	43	438 [185 ± 87]	(Bonnet-Lebrun, A.-S., Catry, P., Clark, T.J., Campioni, L., Kuepfer, A., Tierny, M., Kilbride, E., Wakefield 2020)
Imperial Shag *Leucocarbo atriceps*	Summer	Chick rearing	40	237	47 [16 ± 10]	(Masello et al. 2010, Quillfeldt et al. 2011)

Species	Season	Stage	Individuals tracked	Foraging trips	Trip distance (km) max [mean ± SD]	Data Source
Penguins						
Gentoo *Pygoscelis papua*	Winter	Non-breeding	25	155	479 [109 ± 80]	(Baylis et al. 2019b, 2020)
	Summer	Incubation/ Chick rearing	45	74	79 [21 ± 16]	(Masello et al. 2010)
Magellanic *Spheniscus magellanicus*	Summer	Incubation/ Chick rearing	63	140	1,115 [298 ± 298]	(Putz et al. 2002, Boersma et al. 2002)
King *Aptenodytes patagonicus*	Winter	Chick rearing	8	32	971 [295 ± 215]	(Baylis et al. 2015b)
Rockhopper[a] *Eudyptes chrysocome*	Summer	Incubation	27	27	514 [216 ± 127]	(Boersma et al. 2002, Baylis et al. 2019b)
	Summer	Chick rearing	130	199	540 [139 ± 109]	(Masello et al. 2010, Pütz et al. 2018); S Crofts unpublished data
Pinnipeds						
South American fur seal[c] *Arctocephalus australis*	Winter - female	Lactation	17	171	674 [132 ± 142]	(Baylis et al. 2018); A Baylis unpublished data
	Spring - female	Lactation	9	42	940 [265 ± 229]	
Southern sea lion *Otaria flavescens*	Summer - female	Lactation	25	93	173 [63 ± 34]	(Baylis et al. 2015a)
Southern Elephant seal *Mirounga leonine*	Summer - female	Post-breeding	10	10	497 [120 ± 42]	F Galimberti and S Sanvito unpublished data

Table S2. Overlap between potential Key Biodiversity Areas (pKBAs) and proposed Marine Managed Areas (MMAs) (the percent of pKBA within MMA)

pKBAs based on FPT method	MMAs				
	Burdwood Bank 1	Burdwood Bank 2	Beauchêne Is.	Inshore	Jason Is.
Black-browed albatross_Beauchêne Is. pKBA	0.0	0.0	2.7	0.0	0.0
Black-browed albatross_New Is. pKBA	0.0	0.0	0.0	14.2	0.0
Black-browed albatross_Steeple Jason Is. pKBA	0.0	0.0	0.0	32.8	44.7
Rockhopper penugin_Steeple Jason Is. pKBA	0.0	0.0	0.0	20.4	24.4
South American fur seal_West Cay pKBA	0.0	0.0	0.0	33.5	15.3
Sooty Shearwater_Kidney Is. pKBA	0.0	0.0	0.0	27.3	0.0

KBAs based on variance in lat.lon method	MMAs				
	Burdwood Bank 1	Burdwood Bank 2	Beauchêne Is.	Inshore	Jason Is.
Black-browed albatross_Beauchêne Is. pKBA	0.8	0.8	0.2	6.9	0.0
Black-browed albatross_New Is._Incubation pKBA	0.0	0.0	0.0	8.8	0.0
Black-browed albatross_Steeple Jason Is._ Incubation pKBA	0.0	0.0	0.0	0.0	0.0
Black-browed albatross_New Is. pKBA	0.0	0.0	0.0	8.5	0.0
Black-browed albatross_Steeple Jason Is._pKBA	0.0	0.0	0.0	16.4	9.5
Rockhopper penugin_Steeple Jason Is. pKBA	0.0	0.0	0.0	20.4	25.5
South American fur seal_West Cay pKBA	0.0	0.0	0.0	33.4	12.9
Sooty Shearwater_Kidney Is. pKBA	0.7	0.7	0.0	6.7	0.0

pKBAs based on habitat preference models	MMAs				
	Burdwood Bank 1	Burdwood Bank 2	Beauchêne Is.	Inshore	Jason Is.
Black-browed albatross_chick rearing pKBA	1.0	1.8	0.0	2.5	0.2
Black-browed albatross_incubation pKBA	0.8	1.0	0.0	1.8	0.2
Gentoo penguin – summer pKBA	0.0	0.0	0.1	24.9	2.6
Gentoo penguin – winter pKBA	0.0	0.0	0.1	7.9	0.7
Rockhopper penguin - chick rearing pKBA	1.9	2.4	0.0	5.1	0.4
Rockhopper penguin – incubation pKBA	0.0	0.6	0.1	8.5	0.9
South American fur seal – spring pKBA	0.0	0.0	0.0	4.4	0.6
South American fur seal – winter pKBA	0.0	0.0	0.0	7.0	0.6
Sooty shearwater - chick rearing pKBA	0.0	0.0	0.0	32.7	0.0

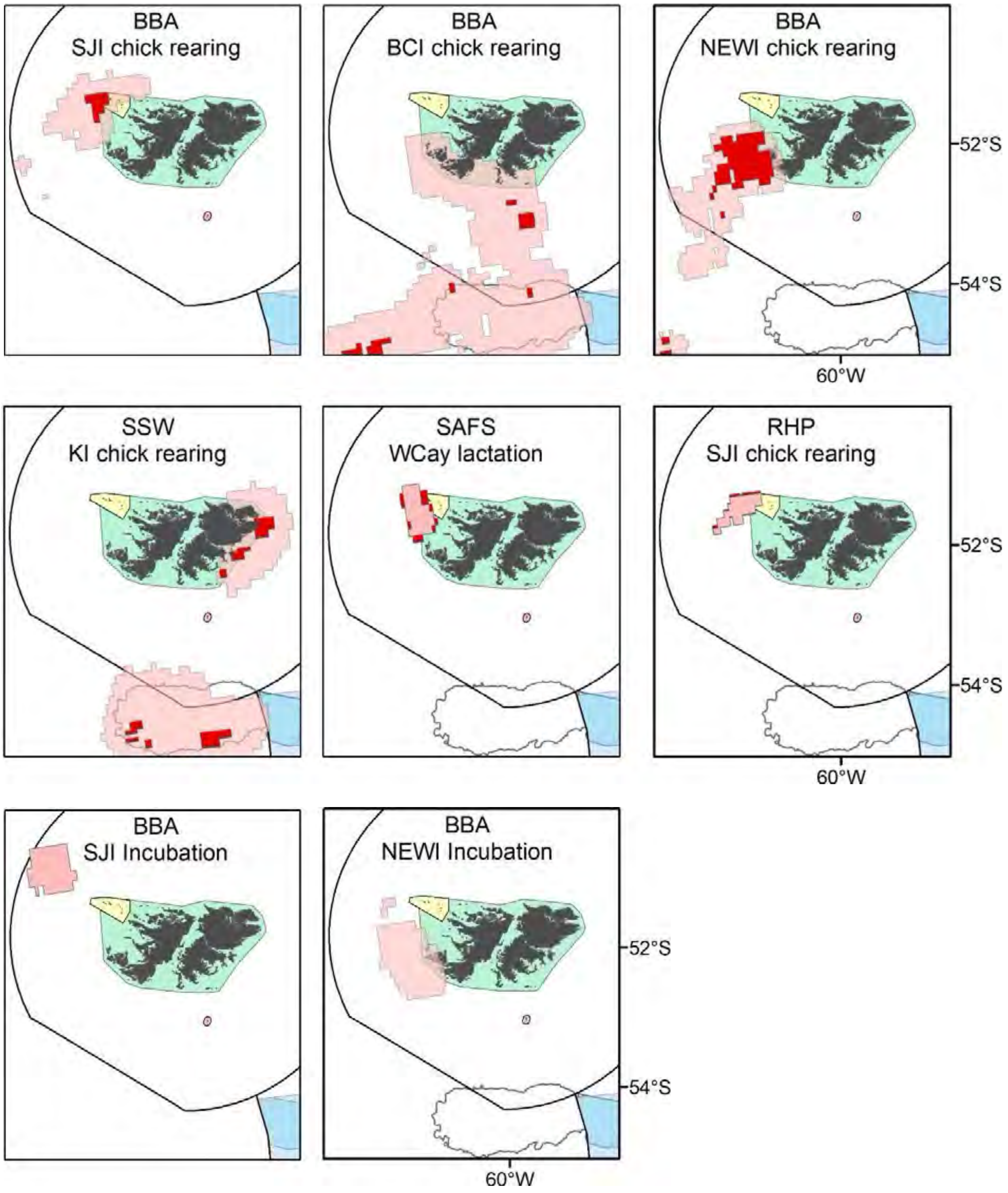


__Fig. S1:__ Potential Key Biodiversity Areas (pKBAs) were identified for four species and six data-groups, where sample size was large enough, and colonies were ≥ 1 % of the global population. BBA = Black-browed albatross, SSW = Sooty Shearwater, SAFS = South American fur seal, RHP = Southern rockhopper penguin. Dark red = pKBA identified using the First Passage Time method to define h value. Light pink = pKBA identified using variance in foraging trip latitude and longitude to define h value.

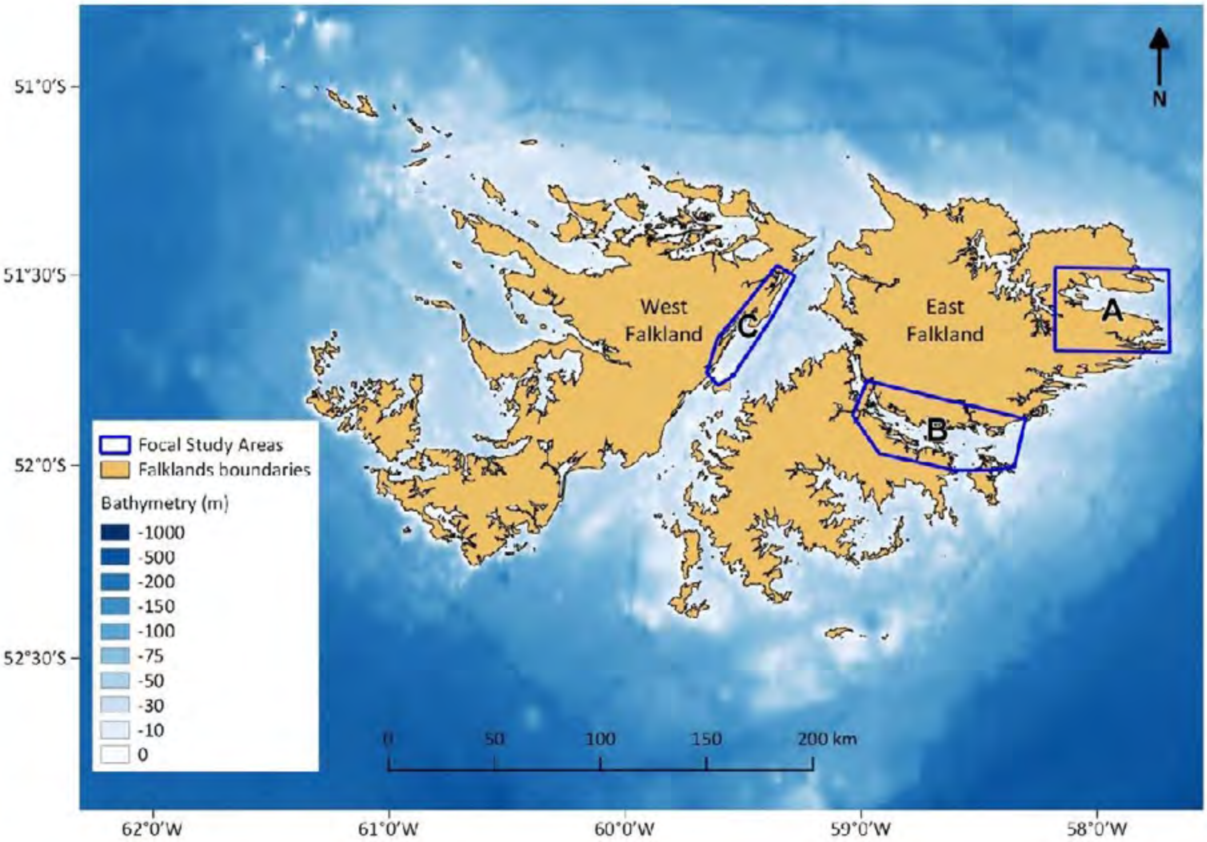


Fig. S2: *Survey locations of SAERI 'Dolphins of the kelp' project. The three areas are (A) Port Stanley, Port William and Berkeley Sound, (B) Choiseul Sound, (C) Port Howard, Many Branch. Source: (Costa and Cazzola 2018).*

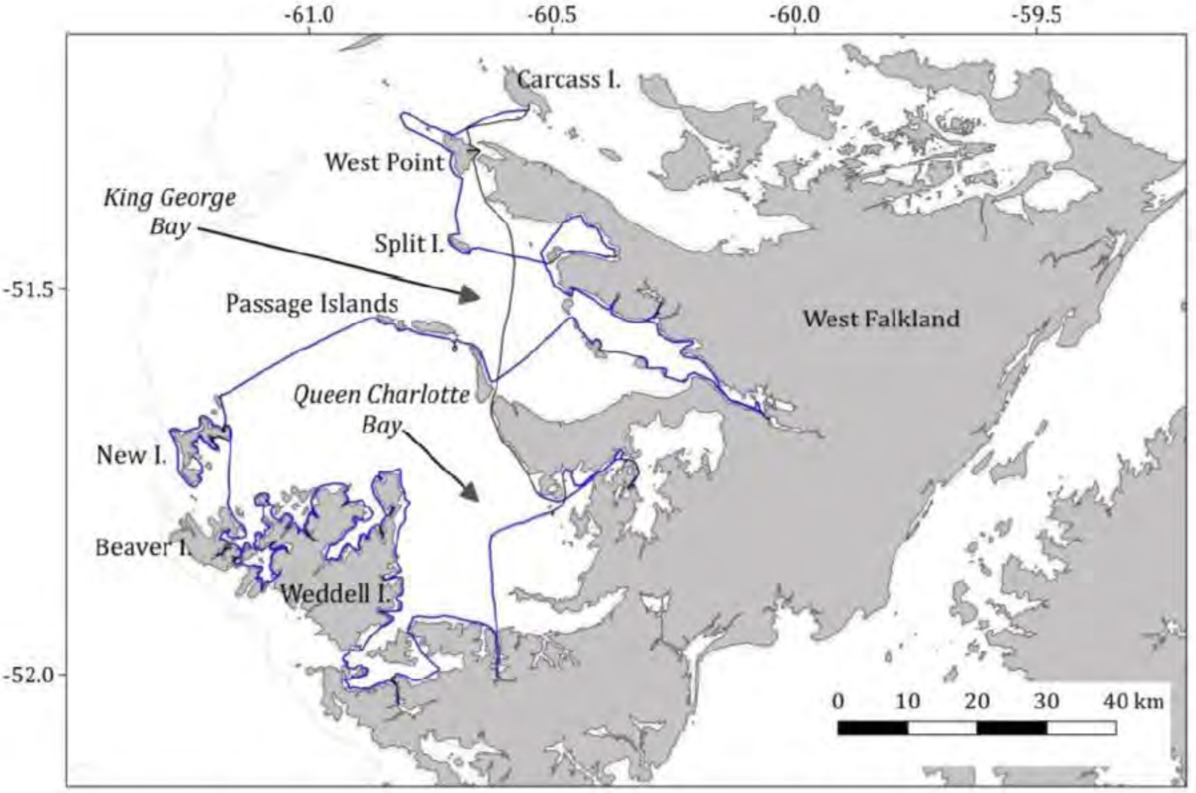


Fig. S3: *Track of SAERI 'Dolphins of the kelp' project during a survey in West Falkland in 2017. Source: (Costa and Cazzola 2018).*

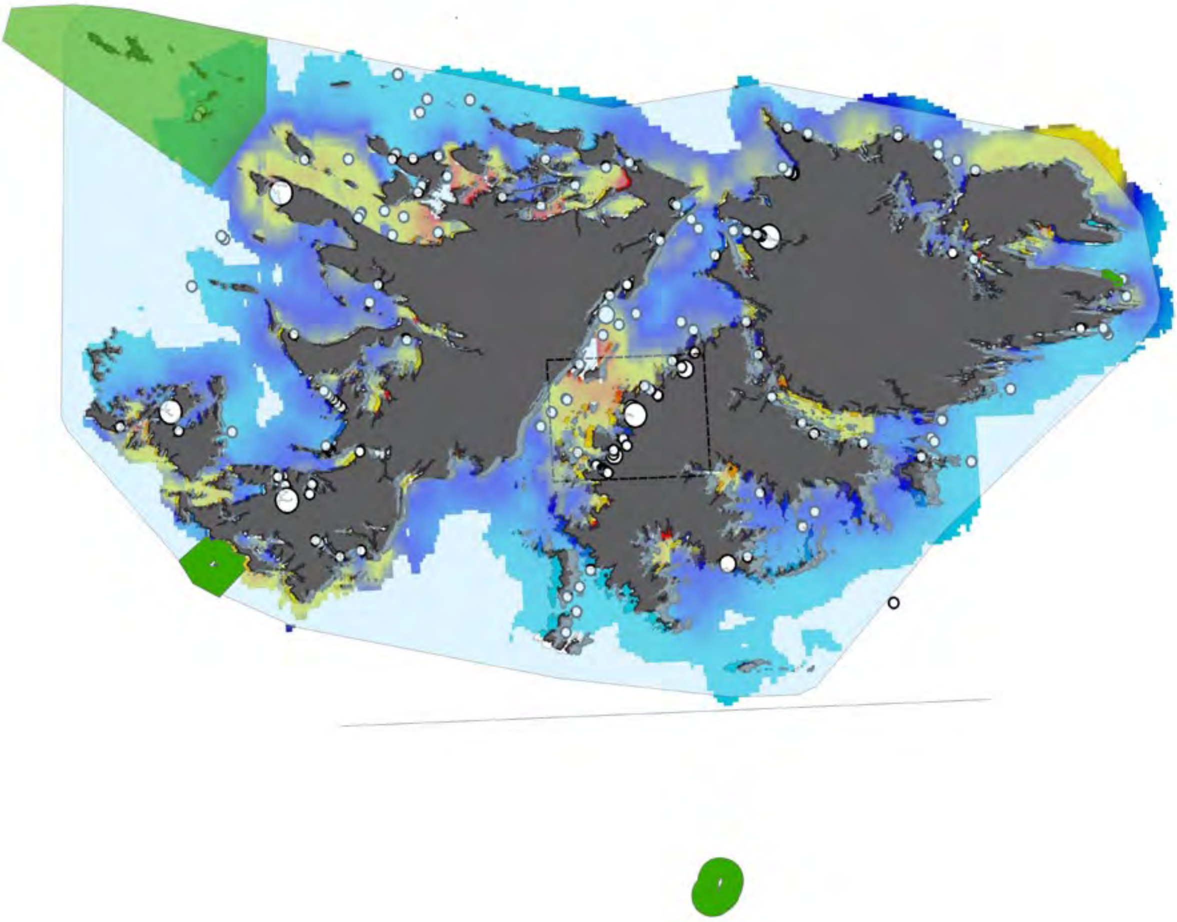


Fig. S4: *Example of the Peale's dolphin predictive model outputs, overlayed onto the proposed Falkland Islands Marine Managed Areas (MMAs), which highlights that the predicted Peale's dolphin hotspots (warmer colors - areas of higher predicted occurrence) primarily fall within the boundaries of the proposed MMAs. Source: (Franchini et al. 2020)*

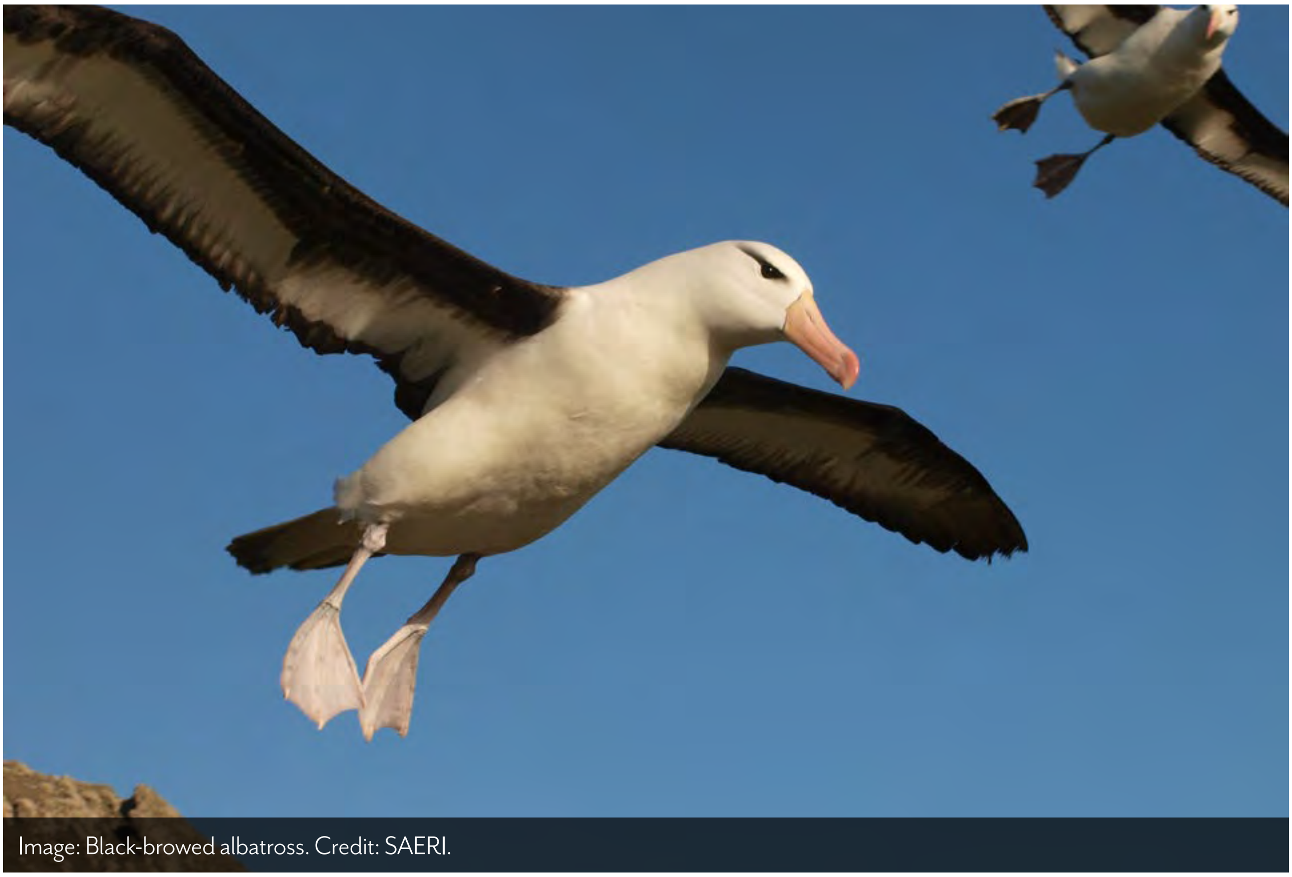


Image: Black-browed albatross. Credit: SAERI.

Table S3 (A). Overlap (% area) between core areas (50% utilization distribution) and potential Key Biodiversity Areas (pKBAs), identified using the First Passage Time method to define *h* value.

		Black-browed albatross pKBA			**Sooty shearwater pKBA**	**Fur seal pKBA**	**Rockhopper pKBA**
Species	**Colony**	**Beauchêne (chick)**	**New Is (chick)**	**Steeple Jason (chick)**	**Kidney Island**	**West Cay**	**Steeple Jason (chick)**
Black-browed albatross	New Is.	2.0	49.0	0.8	0.0	7.4	0.3
Black-browed albatross	Steeple Jason Is.	0.0	5.6	13.3	0.0	38.9	25.7
Black-browed albatross	Beauchêne Is.	20.9	5.5	0.0	4.6	0.0	0.0
Rockhopper penguin	Steeple Jason Is.	0.0	0.0	94.1	0.0	100.0	100.0
Falklands fur seal	West Cay	0.0	2.3	36.4	0.0	99.9	38.1
Sooty shearwater	Kidney Is.	0.0	0.0	0.0	34.8	0.0	0.0
Species	**Data group**						
Flying seabirds							
Black-browed albatross	chick-rearing	10.5	17.0	3.0	2.3	9.6	5.9
	incubation	1.6	5.0	1.0	0.0	2.3	1.9
Imperial shag	chick-rearing	0.0	7.4	28.4	0.0	28.4	28.4
Sooty shearwater	chick-rearing	*See above*					
Penguins							
Gentoo penguin	incubation/ chick-rearing	0.0	30.0	0.0	0.0	0.0	0.0
	non-breeding	0.0	1.7	0.3	1.3	5.2	1.4
King penguin	chick-rearing	0.0	0.0	0.0	0.0	0.0	0.0
Magellanic penguin	summer	0.3	2.5	0.0	1.4	0.5	0.0
Rockhopper penguin	chick-rearing	0.0	0.0	0.0	0.0	0.0	0.0
	incubation	0.4	10.0	1.4	0.0	1.5	1.5

Pinnipeds							
South American fur seal							
winter	lactating female	0.0	0.5	7.4	7.1	0.0	21.1
spring	lactating female						
Southern sea lion	lactating female	0.0	0.0	0.0	0.0	0.0	0.0
Southern elephant seal	pre-moult female	0.0	0.0	0.0	2.1	0.0	0.0

Table S3 (B). As in S4(A) except using potential Key Biodiversity Areas (pKBAs) identified via variance in foraging trip latitude and longitude to define *h* value.

		Black-browed albatross pKBA					**Sooty shearwater pKBA**	**Fur seal pKBA**	**Rockhopper pKBA**
Species	**Colony**	**Beauchene (chick)**	**New Is (chick)**	**New Is (incubation)**	**Steeple Jason (chick)**	**Steeple Jason (incubation)**	**Kidney Island**	**West Cay**	**Steeple Jason (chick)**
Black-browed albatross	New Is.	43.6	82.6	58.9	0.6	17.0	0.0	0.0	5.3
Black-browed albatross	Steeple Jason Is.	3.3	14.0	17.4	24.1	84.6	0.1	0.0	32.7
Black-browed	Beauchêne								
albatross	Is.	95.1	14.2	3.9	0.0	0.0	35.1	0.0	0.0
Black-browed albatross (incubation)	New Is.	23.8	34.7	29.7	0.5	8.3	0.0	0.0	0.9
Black-browed albatross (incubation)	Steeple Jason Is.	1.0	1.0	0.8	4.4	13.9	24.1	0.0	3.9
Rockhopper penguin	Steeple Jason Is.	0.0	0.0	0.0	100.0	0.0	0.0	78.1	100.0
Falklands fur seal	West Cay	0.0	28.9	23.5	97.9	0.0	0.0	96.8	39.6

Sooty shearwater	Kidney Is.	67.8	0.0	0.0	0.0	0.0	97.9	0.0	0.0
Below is all									
Species	**Data group**								
Penguins									
Gentoo penguin	incubation/chick-rearing	41.5	41.5	41.5	0.0	0.0	58.5	0.0	0.0
	non-breeding	1.3	4.1	4.3	8.7	0.0	18.4	3.9	1.6
King penguin	chick-rearing	0.0	0.0	0.0	0.0	0.0	10.3	0.0	0.0
Magellanic penguin	summer	18.3	3.3	2.6	0.9	0.0	16.3	0.2	0.0
Rockhopper penguin	chick-rearing	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0
	incubation	22.2	17.3	15.5	2.6	1.5	5.2	1.2	1.5
Pinnipeds									
South American fur seal									
winter	lactating female	0.0	6.0	4.6	20.1	0.0	4.4	19.5	7.7
spring	lactating female	7.1	7.4	7.0	7.4	0.1	2.1	3.2	1.5
Southern sea lion	lactating female	28.8	0.0	0.0	0.0	0.0	6.5	0.0	0.0
Southern elephant seal	pre-moult female	0.0	0.0	0.0	0.0	0.0	14.1	0.0	0.0

Table S4 (A). Overlap (% area) between potential Key Biodiversity Areas (pKBAs) (identified using a *h* value calculated through First Passage Time analysis) and the predicted spatial usage of marine predators breeding at the Falkland Islands, for which reliable tracking and population data were available.

	Black-browed albatross pKBA			Sooty shearwater pKBA	Fur seal pKBA	Rockhopper pKBA
Data group	**Beauchêne**	**New Is (chick)**	**Steeple Jason (chick)**	**Kidney Island**	**West Cay**	**Steeple Jason (chick)**
Black-browed albatross chick-rearing	0.3	1.9	0.3	1.1	0.6	0.7
Black-browed albatross incubation	0.1	1.2	0.2	0.9	0.1	0.5
Falklands fur seal Spring	0.0	7.6	1.3	4.3	0.7	2.7
Falklands fur seal winter	0.1	4.5	0.8	2.6	0.7	1.6
Gentoo penguin summer	0.3	6.2	2.0	6.6	2.9	2.7
Gentoo penguin winter	0.7	5.8	1.0	3.2	1.0	2.1
King penguin	0.4	0.0	0.0	0.0	0.8	0.0
Magellanic penguin summer	0.2	1.5	0.3	1.0	0.3	0.5
Rockhopper penguin chick-rearing	0.3	1.9	0.3	1.1	0.6	0.7
Rockhopper penguin incubation	0.4	3.4	0.6	2.0	0.7	1.3
Sooty shearwater summer	0.5	0.0	0.0	0.0	5.6	0.0
Southern elephant seal post-moult	1.3	0.0	0.0	0.0	0.2	0.0
Southern sea lion summer	1.4	10.6	2.6	8.8	1.5	5.0

Image: Jason Islands. Credit: SAERI.

Image: South American fur seal. Credit: SAERI.

Table S4 (B). As in S5(A) except using proposed Key Biodiversity Areas (pKBAs) identified via variance in foraging trip latitude and longitude to define *h* value.

	Black-browed albatross pKBA			**Sooty shearwater pKBA**	**Fur seal pKBA**	**Rockhopper pKBA**
Data group	**Beauchêne**	**New Is (chick)**	**Steeple Jason (chick)**	**Kidney Island**	**West Cay**	**Steeple Jason (chick)**
Black-browed albatross chick-rearing	15.4	6.9	3.7	10.2	0.7	0.8
Black-browed albatross incubation	3.5	2.3	2.6	1.0	0.5	0.7
Falklands fur seal Spring	13.8	18.0	14.1	7.1	2.7	3.3
Falklands fur seal winter	9.9	13.1	8.8	5.7	1.6	2.0
Gentoo penguin summer	28.4	10.7	13.5	18.1	2.5	5.1
Gentoo penguin winter	21.0	15.3	10.1	11.3	2.1	2.6
King penguin	6.6	0.0	1.0	8.4	0.0	0.0
Magellanic penguin summer	9.0	4.5	2.9	5.4	0.5	0.7
Rockhopper penguin chick-rearing	15.4	6.9	3.7	10.2	0.7	0.8
Rockhopper penguin incubation	14.5	6.7	6.2	7.2	1.3	1.6
Sooty shearwater summer	44.0	0.0	0.0	60.9	0.0	0.0
Southern elephant seal post- moult	38.2	0.2	0.0	9.1	0.0	0.0
Southern sea lion summer	35.5	16.5	22.2	14.9	4.8	6.9
	15.4	6.9	3.7	10.2	0.7	0.8

	Black-browed albatross pKBA				
Data group	**New Is. Incubation**	**Steeple Jason Incubation**			
Black-browed albatross chick-rearing	3.0	1.5			
Black-browed albatross incubation	2.4	2.0			
Falklands fur seal Spring	12.3	4.2			
Falklands fur seal winter	7.2	3.5			
Gentoo penguin summer	8.1	0			
Gentoo penguin winter	9.3	1.0			
King penguin	0	0			
Magellanic penguin summer	2.6	1.7			

Rockhopper penguin chick- rearing	3.0	1.5			
Rockhopper penguin incubation	5.6	0.4			
Sooty shearwater summer	0	0			
Southern elephant seal post- moult	0.2	0			
Southern sea lion summer	15.2	0			

Image: Southern sea lions. Credit: SAERI.

Table S5. A GAP analysis to improve the coverage of tracking data. Species and conservation scores were from Augé et al. 2008 and priority actions are suggested for species with values ≥ 3. Most species first require population data to quantify to understand global importance and priority sites. BCI = Beauchêne Island, BIRD = Bird island, EC = East Cay, GRAND = Grand Jason Island, GC = Grave Cove, PBI = Pebble Is, SI = Saunders Island, SRK = Seal Rock, SJI = Steeple Jason Island, WC = West cay. See Appendix S3 for locations of key sites. NA – reliable data not available.

Species – Common name	Species – Latin name	IUCN status	Local population size (breeding pairs/pups)	Global population (%)	Falkland Islands occurrence	Conservation Scores from Augé et al. 2008	Migratory	Suggested priority action	Source
Great shearwater	*Puffinus gravis*	LC	NA	-	few	1	Y	none	(Woods and Woods 1997)
Southern elephant seal	*Mirounga leonine*	LC	667	< 1 %	common	1	Y	none	F. Galimberti unpublished data
Kelp gull	*Larus dominicanus*	LC	NA	-	abundant	1	N	none	(Woods and Woods 1997)
King penguin	*Aptenodytes patagonicus*	LC	~700	< 1 %	few	1	N	none	(Pistorius et al. 2012)
Fairy prion	*Pachyptila turtur*	LC	NA	-	NA	2	Y	none	(Woods and Woods 1997)
Rock shag	*Phalacrocorax magellanicus*	LC	NA	-	abundant	2	N	none	(Woods and Woods 1997)
Southern sea lion	*Otaria flavescens*	LC	5,000	6	common	2	N	none	(Baylis et al. 2015c)
Brown skua	*Stercorarius antarcticus*	LC	NA	-	common	3	Y	Census	(Woods and Woods 1997)
Common diving petrel	*Pelecanoides urinatrix*	LC	NA	-	NA	3	Y	Census	(Woods and Woods 1997)
Grey-backed storm-petrel	*Garrodia nereis*	LC	NA	-	NA	3	Y	Census	(Woods and Woods 1997)
South American tern	*Sterna hirundinacea*	LC	NA	-	common	3	Y	Census	(Woods and Woods 1997)
Wilson's storm-petrel	*Oceanites oceanicus*	LC	NA	-	NA	3	Y	Census	(Woods and Woods 1997)

Imperial shag	*Phalacrocorax atriceps*	*LC*	NA	-	abundant	3	N	Census	(Woods and Woods 1997)
Dolphin gull	*Leucophaeus scoresbii*	LC	NA	-	abundant	3	N	Census	(Woods and Woods 1997)
White-chinned petrel	*Procellaria aequinoctialis*	VU	NA	-	few	3	Y	Census	(Woods and Woods 1997)
Magellanic penguin	*Spheniscus magellanicus*	NT	NA	-	abundant	3	Y	Census	(Woods and Woods 1997)
Black-browed albatross	*Thalassarche melanophris*	LC	485,000	76	abundant	3	Y	Tracking data BIRD, SAU	Falklands Conservation unpublished data
Slender-billed prion	*Pachyptila belcheri*	LC	>1 million	NA	abundant	3	Y	Census and establish tracking data BIRD, NEW	(Catry et al. 2003)
Sooty shearwater	*Puffinus griseus*	NT	140,000	6	abundant	3	Y	Interannual tracking	(Clark et al. 2019)
South American fur seal	*Arctocephalus australis*	LC	36,500	48	abundant	3	N	Tracking data WC, EC, SRK	(Baylis et al. 2019a)
Southern giant petrel	*Macronectes giganteus*	LC	21,000	43	abundant	3	N	Establish tracking data (i.e., juveniles)	Falklands Conservation unpublished data
Gentoo penguin	*Pygoscelis papua*	NT	130,000	30	abundant	4	N	SI, GC, PBI,	(Baylis et al. 2013a)
Southern rockhopper penguin	*Eudyptes chrysocome*	VU	317,000	36	abundant	5	Y	BCI, SJI, BIRD, GRAND	(Baylis et al. 2013b)
Falkland steamer duck	*Tachyeres brachypterus*	LC	NA	100 (endemic)	abundant	5	N	Track juveniles/ identify aggregations during the non-breeding season	(Woods and Woods 1997)

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CHAPTER 4

ECONOMIC IMPLICATIONS

Image: Gentoo penguins. Credit: SAERI.

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CHAPTER 4.1: AN ASSESSMENT OF THE CURRENT AND CURRENTLY PROPOSED ECONOMIC ACTIVITIES IN THE FALKLANDS INTERIM AND OUTER CONSERVATION ZONES

This work was commissioned by SAERI in 2019 and elements of the economic landscape of the Falkland Island will have changed. Furthermore, the findings of this chapter are based on assumptions regarding MMAs and categories, described within. This format of this chapter deviates slightly from the previous chapters. This chapter includes views and information provided by key public and private sector stakeholders at the time the report was written.

SUMMARY

In support of SAERI's Fine Scaling the Design of Falkland Islands Marine Management Areas Project, the current study (presented in this chapter) was commissioned. It aims to provide an assessment of the current and currently proposed economic activities in the areas of the Falklands Interim and Outer Conservation Zones that could potentially overlap with areas highlighted during the Marine Spatial Planning (MSP) process, and subsequently refined in the Fine Scaling the Design of Falkland Islands Marine Management Areas Project, as potential Marine Management Area (MMA) sites through the presented analysis and review. The study presents a brief overview of the Falkland Islands (FI) Economy as it relates to this and then examines the specific economic activities that overlap. Chapter 4.2 provides an assessment of the (economic) impact of proposed MMA sites on these activities.

Fishing is a major contributor to the FI economy, accounting 35-59% of GDP (Gross Domestic Product) between 2007 and 2016 and with fishing license fees and corporation tax being important revenues for the FI government. It also has important feed-on effects to a range of other industries,e.g., logistics such as transhipment, fuel, provisions and transportation. There is some spatial overlap between fishing activity and the proposed MMAs; the MMA designs on and around the Burdwood Bank overlap with the longline sector, while the inshore MMA overlaps with small-scale fishing activities for snow-crab and mullet.

Offshore hydrocarbon exploration has taken place in FI waters and a number of current production licenses are held, though commercial production has not yet begun. Exploration has stimulated the economy and generated revenue to government through acreage rentals and corporation tax on current operations, contributing significantly to the Islands' GVA (Gross Value Added). Should oil production go ahead an even greater impact is anticipated, with a further 9% royalty to be paid on production. There is no overlap with licensed oil blocks and the MMAs. The only overlap may be with rig chain storage on the seabed in the inshore (outside of Port areas).

Tourism is a smaller but growing sector in the FI economy, accounting around 1.3% of GDP in 2016. It is the primary employer of 89 people (4.9% of workforce) and the secondary employer of a further 96. It provides direct revenue to the government in the form of passenger levies and vessel-related duties for cruise-ships. Tourist expenditure also provides some stimulus to local businesses and can be a particularly important source of income to those landholdings that engage in marine-related tourism on the Outer Islands. There is overlap between tourism in Camp (expeditionary vessel visits) and MMAs.

There is a local yachting community and a number of leisure craft are kept on the Island and may be moored at sites such as the Canache in Stanley harbour area. Yachts also visit the Islands (32 – 47 per year between 2016 and 2018) for cruising or chartering purposes and can spend in the region of £96,000 to £178,600 per year. There is some overlap between MMAs and yacht visits around the Islands outside of the Port areas.

In terms of harbours, shipping and the ferry; ports are key areas for the Islands which depend on exports of fish, meat and wool to drive the economy and imports of many key goods such as fuel, food, commercial and household goods. Industries such as fishing, tourism and oil, depend on these port/harbour areas for their activities. Port areas also provide revenue to government in the form of levies and dues, e.g. passenger levy, customs charges, and harbour dues. Ramps, jetties and anchorage sites around Camp (i.e. outside of Port Stanley) are essential infrastructure for the ferry (Concordia Bay) and other (e.g. expeditionary cruise) vessel visits, and upgrades are planned for a number of these in the coming years. The ferry service itself is a key link between East and West Falkland, transporting passengers, vehicles and cargo, and providing bulk deliveries of fuel to Fox Bay. It also provides a key shipping and commercial haulage (e.g. wool, sheep, goods, construction materials) service to the Outer Islands and is essential to three of these which have no other transport links. Port areas fall outside the proposed MMAs, but ramps, jetties and anchorage sites around Camp (outside of port areas) do overlap, as does much of the ferry route.

Aquaculture, the farming of marine and freshwater organisms like

fish, molluscs, crustaceans, algae and aquatic plants, is currently a small sector on the Islands with a brown trout farm at Fitzroy Sound.

The environmental science, conservation and research sector could be considered to be made up of research organizations, consultancies and non-governmental organizations working specifically on the natural environment and independent researchers who may be linked to such organizations.
They attract international funds to FI in the form of grants, donations and consultancy, or through having their ships flagged (and often resupplied) in FI. They employ about 25 people, hold assets and may also contribute in the form of volunteer hours invested or through generation of knowledge and data for the Islands, as well as providing a means of skills and knowledge transfer. Many of their areas of activity overlap with areas proposed as MMAs.

INTRODUCTION, BACKGROUND AND OBJECTIVES

The South Atlantic Environmental Research Institute's (SAERI) Fine Scaling the Design of Falkland Islands Marine Management Areas Project commissioned this study to assist it with an assessment of current and currently proposed economic activities in the areas of the Falklands Interim and Outer Conservation Zones that overlap with areas proposed as potential Marine Management Area (MMA) sites.

Background

The Falkland Islands is a United Kingdom Overseas Territory that lies about 300 nautical miles to the east of the South American mainland, and comprises two large islands and around 776 smaller ones (Fig. 4.1). In the waters around the Islands, the Falklands Interim Conservation and Management Zone (FICZ; established in 1986) and the Falklands Outer Conservation Zone (FOCZ), established in 1990 and extending out to 200 nautical miles, give the Falkland Islands control over its fishery [1].

The population of the Islands is small, 3,398 people in 2016, but it has a strong economy, providing for a high standard of living and a wide range of public services supplied by the Falkland Islands Government (FIG). The economy is largely driven by the fishing industry, which accounts for much of the exports, although wool, meat and tourism also feature [2].

The marine environment and seascapes are of great importance to the Islands, not just because fishing constitutes a large chunk of the economy, but also because the Islands depend quite heavily on imports of industrial and consumer goods, fuel and a good deal of foodstuffs [2], much of which come by sea. Furthermore, (marine) hydrocarbon exploration has already provided a stimulus to the economy, and it is anticipated to have a greater impact should oil production go ahead [2]. Tourism is a growing industry on the Islands, with the vast majority of tourists coming by cruise ship – 92% or 62,505 out of 68,070 tourists in 2018 [3], largely to enjoy the marine and coastal environments of the Islands and the wildlife they have to offer. Studies have indicated that much of Falkland Islands residents' leisure activities take place around coastal areas, and, based on FIGAS flight data, much of the land-based tourist movement on the Falkland Islands is to and from a number of outlying islands, such as Sea Lion, Saunders, Pebble and Carcass Islands, which is to a degree probably related to marine wildlife on at least some of these [5].

It is presumably against this backdrop that the Islands Plan (2014-2018) committed to sustainable economic and social development, and specifically to "*implement appropriate land and marine spatial planning frameworks to ensure the preservation and management of both the terrestrial and marine environments of the Falkland Islands*" [6: page 26]. To '*enable coordinated and sustainable management of the marine environment*' [7: page 5], the Marine Spatial Planning Process was initiated in the Falkland Islands in 2014.

Marine Spatial Planning (MSP) in the Falkland Islands began in July 2014, as a Darwin Plus funded project (MSP Phase I), with the aim of initiating and forming a framework for the MSP process in the Falkland Islands [7]. This was continued in MSP Phase II (2016-2018), in which the South Atlantic Environmental Institute (SAERI), on behalf of FIG, identified potential areas suitable as Marine Managed Areas (MMAs) against international criteria [8]. Building on this work, the Darwin Plus funded Fine Scaling the Design of Falkland Islands Marine Management Areas project currently being undertaken by SAERI is conducting key baseline work for the effective design and management of these sites [8], and has further refined the designs beyond MSP II including in consultation with the Project Management Group (PMG)[1]. It is in the context of this latest project that SAERI has commissioned the study outlined in this chapter.

Objectives of the Study

This study aims to provide an assessment of the current and currently proposed economic activities (as of March 2019) in the areas of the Falklands Interim and Outer Conservation Zones that overlap with the areas highlighted during the Marine Spatial Planning (MSP) process and as refined through discussion with the PMG as potential MMAs (Fig. 4.2)[2], through the presented analysis and review.

Methods

Data on the economic activities that overlap with the MMAs of the Falkland Islands were collected through consultation with relevant stakeholders. Secondary data were kindly provided by a number of stakeholders, including government and non-governmental organizations, or were obtained from online, publicly accessible information and databases (such as TradeMap or Comex), as pointed out in individual sections of this chapter.

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[1] The PMG consists of members of Falkland Islands Government (Directorate of Natural Resources, Directorate of Policy and Economic Development, Directorate of Mineral Resources), Industry (FIPLA and FIFCA), SMSG and SAERI.

[2] **It is important to note that stakeholder consultation** could result in different economic consequences to those described in the findings of this report. This chapter and its findings are based on the assumptions and categorization detailed in this chapter.

Fig. 4.1: *Map of the Falkland Islands and the Falkland Islands Interim and Outer Conservation Zones (FICZ and FOCZ), indicating the Falkland Islands positioning in the South-west Atlantic. The Burdwook Bank is indicated in pale blue.*

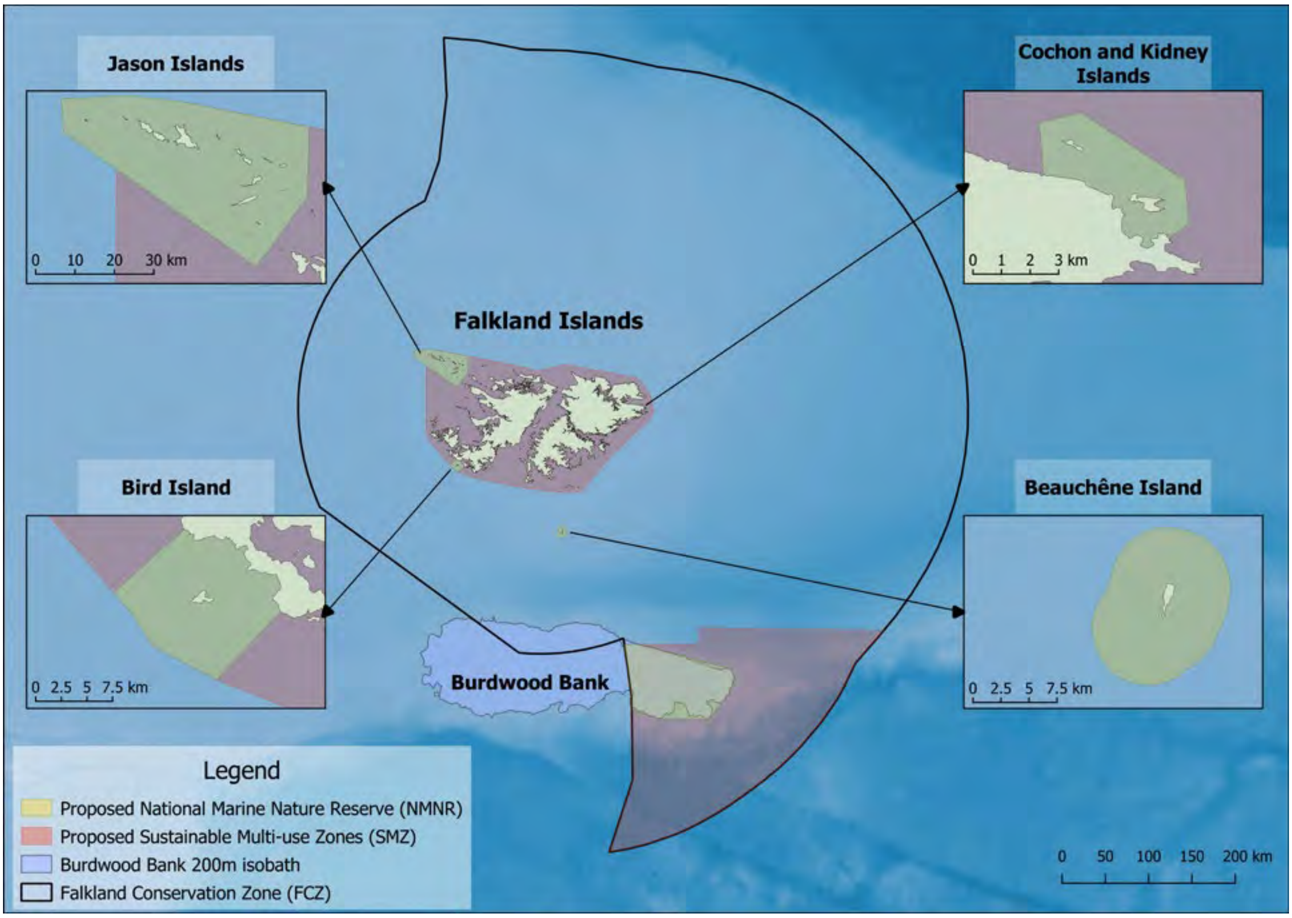

Fig. 4.2: *Map showing the Falkland Islands Conservation Zones (FCZ) and the proposed Marine Management Areas (MMAs). These include a Sustainable Multi-use Zone (SMZ) and National Marine Nature Reserve (NMNR) in the Burdwood Bank area, Beauchêne Island NMNR and the inshore SMZ with nested NMNRs of the Jason Islands, Bird Island, and Cochon and Kidney Islands.*

ECONOMIC ACTIVITIES IN THE FALKLAND ISLANDS

While the current study is interested in only those economic activities that overlap with the proposed MMA sites, it is worthwhile first providing the broader context of the Falkland Islands economy before delving into the relevant economic activities in further depth.

The Falkland Islands economy had a nominal gross domestic product equal to FKP£283.4 million or FKP£93,300 per capita in 2016, of which fishing (as aquaculture is currently limited to a single, small- scale venture) accounted the lion's share (Fig. 4.3). Annual GDP is quite volatile, as is annual Gross Value Added (GVA; Fig. 4.4), because of the importance of fishing and hydrocarbons to the economy [2], and the inter-annual variability in fish catches, oil prices and activity in the Falkland Islands hydrocarbon sector.

Unsurprisingly, given their importance to the economy, fisheries are the largest source of government revenue in the form of fishing licenses, followed by corporation tax, personal tax and investment income (Fig. 4.5).

Export is important to the economy, with fish being the Islands' greatest export – valued around FKP£152.5 million in 2017 by FIG with reference to the United Nations Comtrade database – followed by wool and meat [2]. Hydrocarbon exploration has contributed to the economy and, should oil production take place in future, this is expected to have a greater impact. Imports are also important for the Islands, with consumer and industrial goods, fuel and much foodstuff being imported [2].

Unemployment is low (1 % in 2016) and labour force participation rate is high (90% in 2016), with reliance on skilled and unskilled migrant labour to fill positions [2]. Public service is the largest employer, followed by agriculture and wholesale and retail trade (Fig. 4.6).

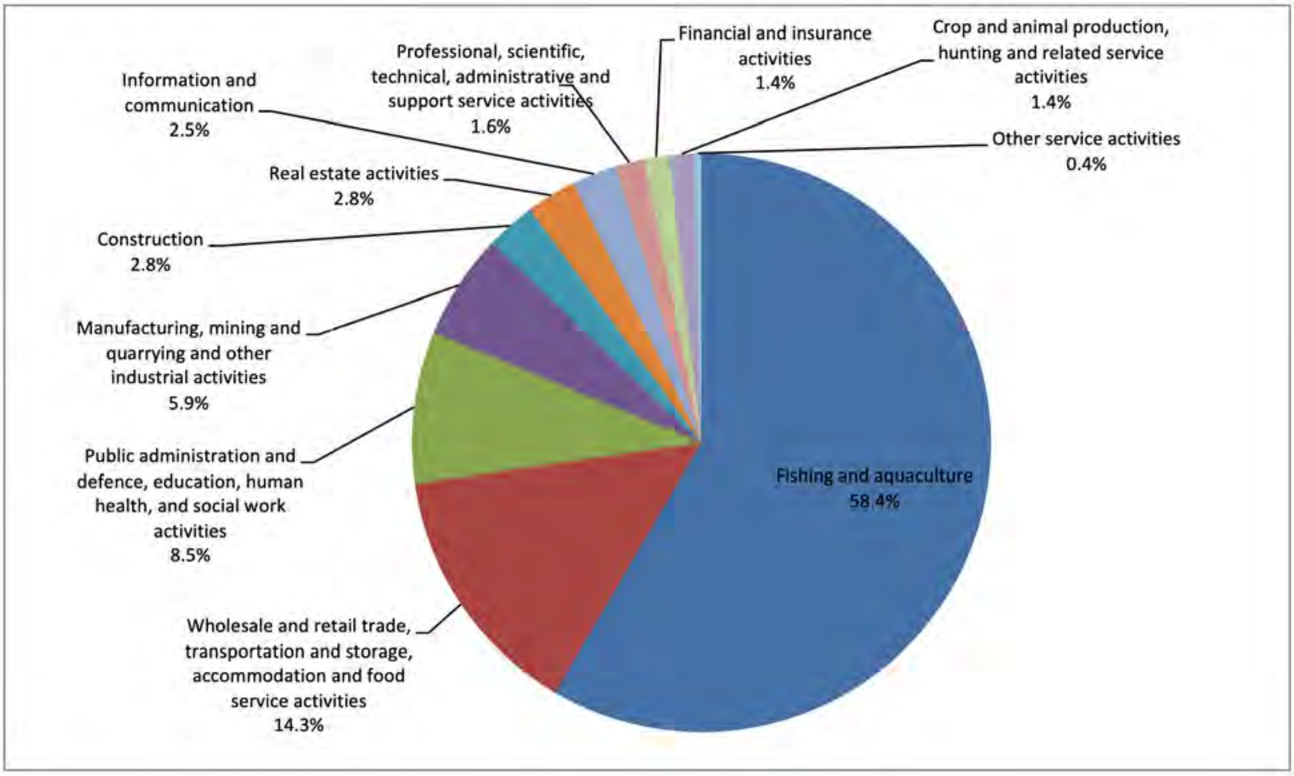

Fig. 4.3: *The contribution of different sectors to the Falkland Islands GDP in 2016, after Fig. 7 in State of the Falkland Islands Economy 2018 Report [2], tourism is not separated out as a sector in the report, as described in text.*

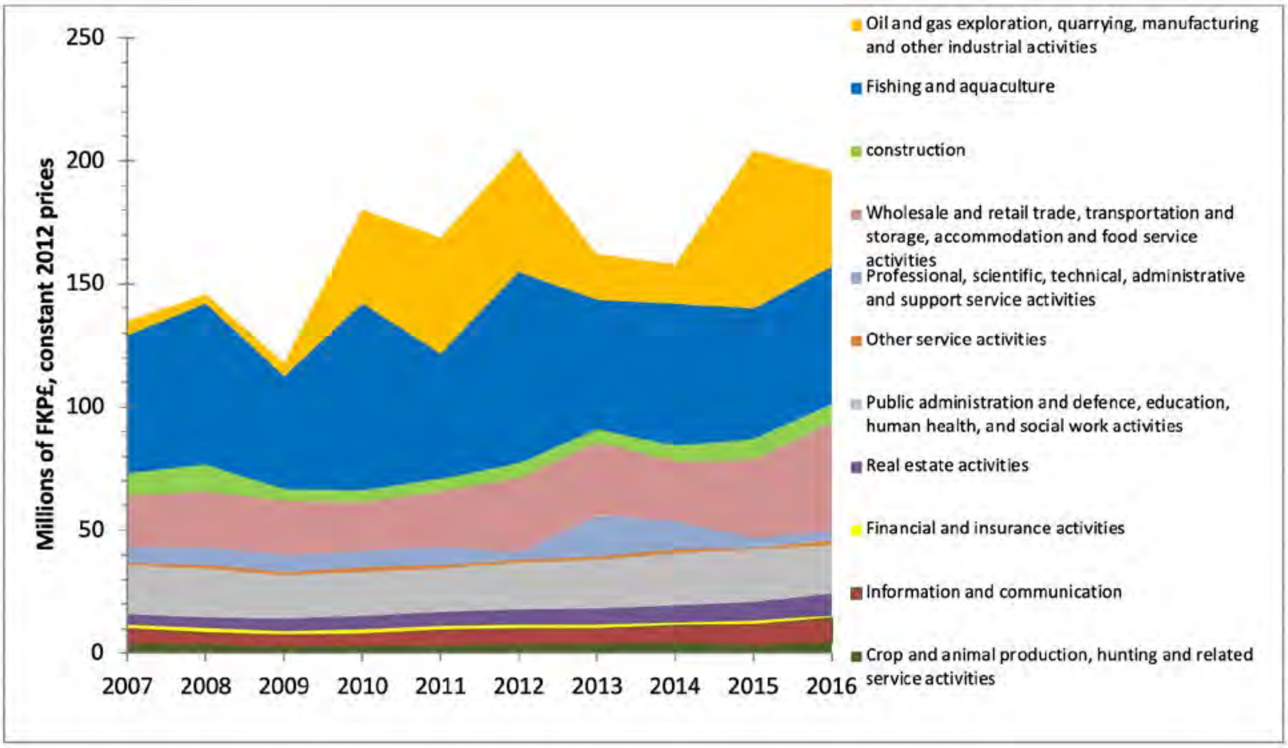

Fig. 4.4: *The contribution of different economic activities to annual Gross Value Added in constant prices, after Fig. 4 in the National Accounts 2007-2016 Report [9].*

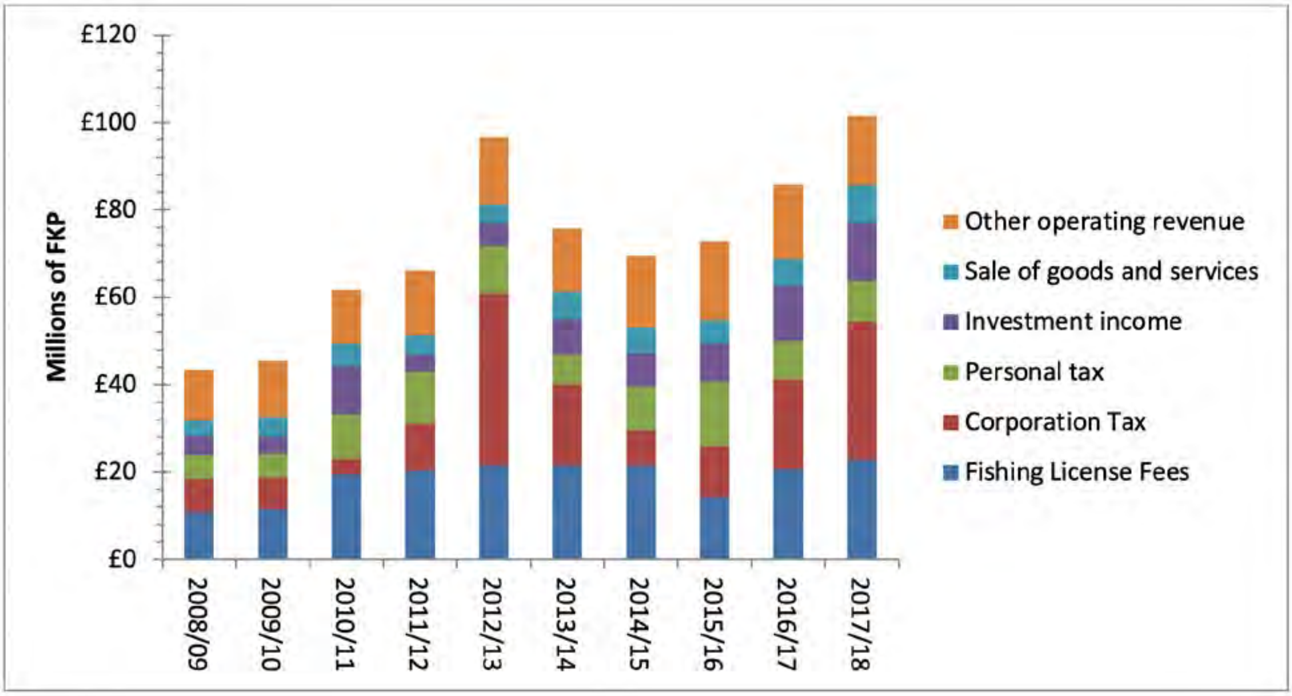

Fig. 4.5: *Revenues earned by Falkland Islands Government 2008/09 to 2017/18, after Fig. 14 in State of the Falkland Islands Economy 2018 Report [2].*

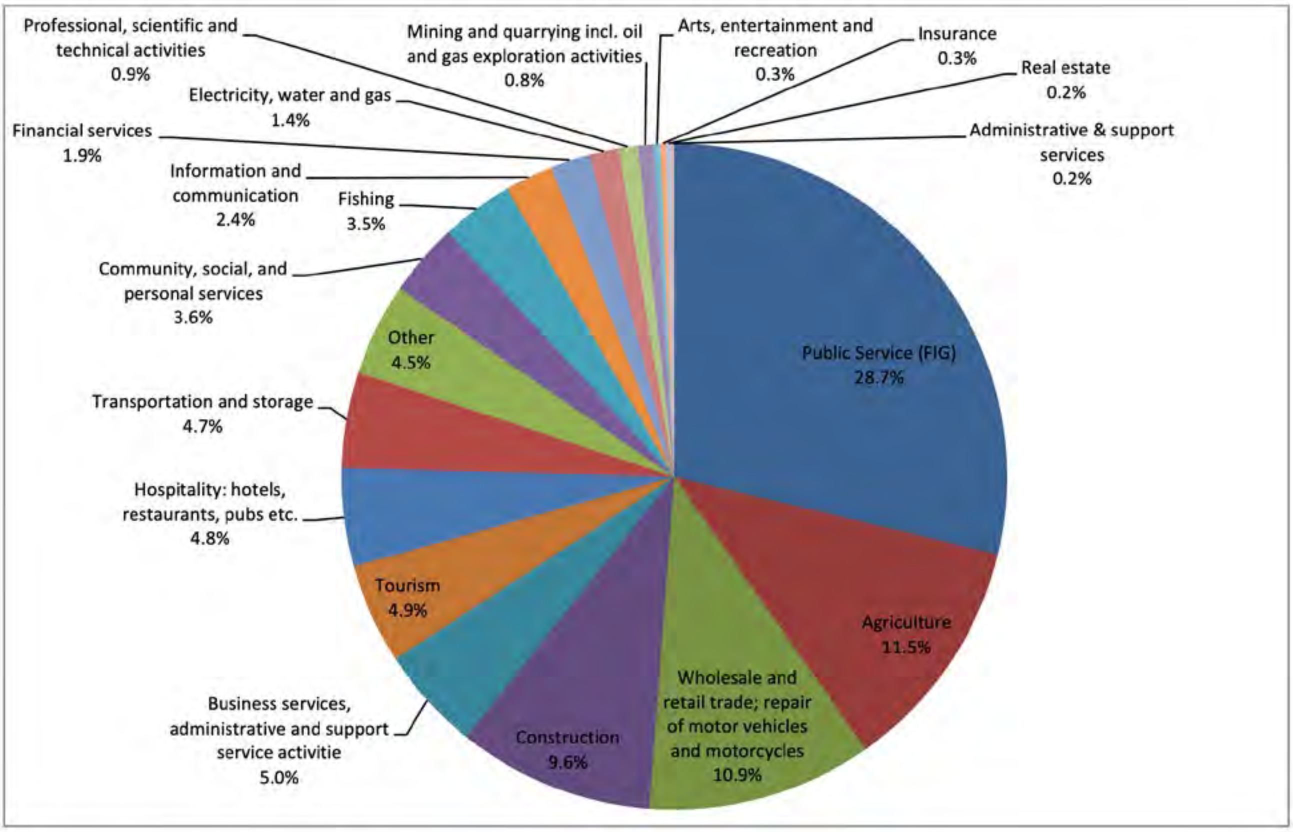

Fig. 4.6: *Proportional employment by industry (excluding military) on the Falkland Islands in 2016, after employment statistics given in Fig. 17 of State of the Falkland Islands Economy 2018 Report [2].*

1. FISHERIES

Overview

Fishing is an important economic activity in the Falkland Islands. It accounted for 58.4% of the Falkland Islands GDP in 2016, fluctuating between 35% and 59% over the 2007 to 2016 period [2]. As discussed above, fishing license fees and the portion fishing companies contribute to corporation tax have been important revenues for FIG. Fishing license fees have generated between £10 and £30 million Falkland Pounds (FKP) a year since 1987, when they were first charged.

It is not the largest employer in the islands (64 local employees; see Fig. 4.6, above), as most crew on vessels are non-residents, and there are economic leakages due to payments to these foreign crew and some profit transfer to foreign companies [1]. However, there has been gradual change in terms of vertical integration of Falkland-owned companies; some of these companies have invested into processing aspects of the value chain in Europe thereby accessing some of the profits of value- adding, there is also a land-based processing facility now established in the Falkland Islands [10]. There is some onshore employment in the fisheries sector and the fishing industry supports a range of other industries and, therefore, employment on the Islands through purchase of goods and services, e.g. logistics such as transhipment, fuel, provisions and transportation.

Additionally, it could be argued that as the fishing sector significantly contributes to FIG revenue, it indirectly helps to support public sector jobs. Some fishing companies also make further investments, albeit that they are minor in comparison to taxation and license fees, into the local economy through investing in scientific studies in support of MSC certification or environmental initiatives, co-funding a scientist position or making vessels available to assist with research cruises from time to time.

In terms of costs, management of the fishing industry cost FKP£5.5 million to government in 2016/17, which was spent on fisheries protection and harbour control, fisheries-related administration and scientific budget [2].

Areas licensed for fishing overlap with some proposed MMAs (Fig. 4.7); fishing is therefore considered in this study. It takes place in the Falklands Interim and Outer Conservation Zones, where commercially exploited species are caught on a variety of licenses (Table 4.1; for further details on species and license types see [11]), and principally with three main vessel types – jiggers, longliners, and trawlers. Although there have also been combination vessels with both jigging and trawling gear that operated in the 1980's and 90's and a number of small-scale, experimental fishing efforts with pots, targeting crab in shallow and deep water.

Fisheries are managed through an individual transferable quota (ITQ) system, where Falkland Islands resident companies hold quotas, although they may engage in joint-ventures with foreign companies. The exception to this is the *Illex* squid fishery where licenses are currently sold to foreign vessels on an annual basis, although this does not exclude it changing to an ITQ system in future. Based on the fishery statistics handbook, there are currently 13 quota- holders engaged in the ITQ managed fisheries (see Table A.5 in [11] for further details). Looking at *Illex* squid fishing, there have been around 100 'B' licenses issued each year since 2011, though considerably fewer licenses were issued in the previous decade with correspondingly lower catches of *Illex* squid in those years. Since 2009 most 'B' *Illex* licenses have been sold to fishing vessels from Taiwan, Korea and Vanuatu (for further details see Table B.1 and B.4 in [11]).

Table 4.1. Fishing license types in the Falkland Islands with associated target species and period of application, after Table A.4 in [11]. Further details may also be found at www.fig.gov.fk/fisheries/overview/license- types.

Licence	Target species	Period of application
First Season		
A	Unrestricted finfish	1989 - 2007
B	Illex and Martialia squid	1993 - present
	Illex squid	1989 - 1992
C	Falkland Calamari (Loligo)	1989 - present
F	Skates and rays	1995 –2007
G	Illex squid and restricted finfish*	1997 - present
W	Restricted finfish**	1994 - 2007
Second Season		
R	Skate and rays	1994 - 2007
X	Falkland Calamari (Loligo)	1991 - present
	All species	1989 - 1990
Y	Unrestricted finfish	1989 - 2007
Z	Restricted finfish**	1989 - 2007
All year		
A	Unrestricted finfish	2008 - present
F	Skates and rays	2008 - present
E	Experimental fishery***	1996 - present
L	Toothfish (Longliners)	mid 1999 - present
S	Blue Whiting and Hoki	1999 - present
W	Restricted finfish**	2008 - present

* The 'G' licence was introduced in 1997. It represents a combination of the 'B' Illex squid licence and 'W' restricted finfish licences. It is limited to trawlers using nets with a minimum mesh size of 90 mm.

** Restricted finfish - Main target species: Patagonotothen ramsayi - Rock cod—PAR Micromesistius australis - Southern blue whiting - BLU Macruronus magellanicus - Hoki - WHI

*** Experimental fishing licences 'E' are issued on an occasional basis to denote exploratory or experimental fishing activities. The 'E' licence included longliners fishing for toothfish up to mid 1999, when the 'L' licence was instituted for this activity. In 2006 the 'E' licence was used to cover access to the Loligo fishery during the monitoring activities undertaken by single vessels. The Scallop fishery, exploratory trawl fishery for grenadiers and longline fishery for kingclip have also been operating on an E licence.

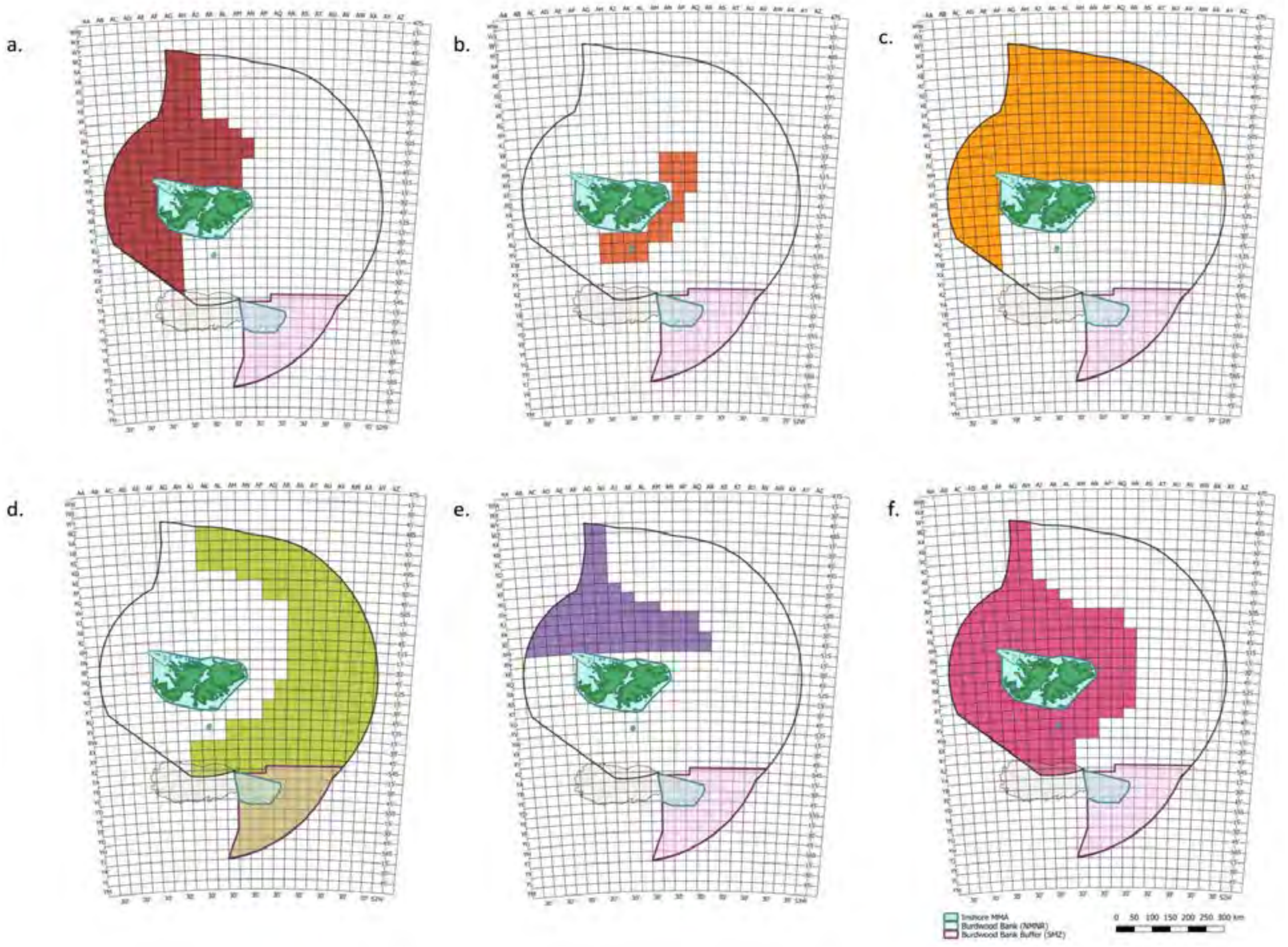

Fig. 4.7: *Illustrative fishing license areas for a) Finfish – licenses A, G and W, b) Falklands calamari (Doryteuthis gahi) – licenses C and X, c) Illex and Martialia squid – license B, d) Longliner – license L, e) Skates and rays – license F, and f) Blue whiting and hoki – license S, in relation to the location of MMAs. Please note that these graphs are purely illustrative and do not encapsulate the full details of fishing license types, which include temporal changes and closures, but rather offer a representative illustration of license location by grid-square. Full details of licenses and associated maps may be found on the Falkland Islands Fisheries Department webpage http://www.fig.gov.fk/fisheries/overview/license-types.*

Table 4.2. Common and scientific names for main retained species in Falkland Islands fisheries.

Common Name	Scientific Name
Austral hake	*Merluccius australis*
Common hake	*Merluccius hubbsi*
Falkland Calamari or Loligo squid	*Doryteuthis gahi*
Falkland mullet	*Eleginops maclovinus*
Grenadiers	*Macrouridae*
Hoki	*Macruronus magellanicus*
Illex squid	*Illex argentinus*
Kingklip	*Genypterus blacodes*
Martialia squid	*Martialia hyadesi*
Patagonian scallop	*Zygochlamys patagonica*
Patagonian toothfish	*Dissostichus eleginoides*
Red cod	*Salilota australis*
Rock cod	*Patagonotothen ramsayi*
Skates and Rays	*Rajidae*
Snow crab	*Paralomis granulosa*
Southern blue whiting	*Micromesistius australis*
Others (bony and cartilligenous fish)	*Osteichthyes and Chondrichthyes*

Since 1989 total annual catches have ranged between 100,000 and 426,814 tonnes, much of the variability being due to fluctuations in Jigger *Illex* squid catches (Fig. 4.8). Unpacking this in more detail for 2007 to present, there have also been inter-annual changes in total Falklands Calamari and Finfish catches (collectively 'trawling'), though these are masked by the larger changes in *Illex* squid caught on board jiggers (Fig. 4.9). For example, catches of rock cod have all but disappeared since 2015, while catches of common hake have increased slightly over the same period.

The variability in *Illex* catches is reflected in the license fees paid to fisheries (Fig. 4.10); the other ITQ-managed fisheries have set license fees that were consistent between years.

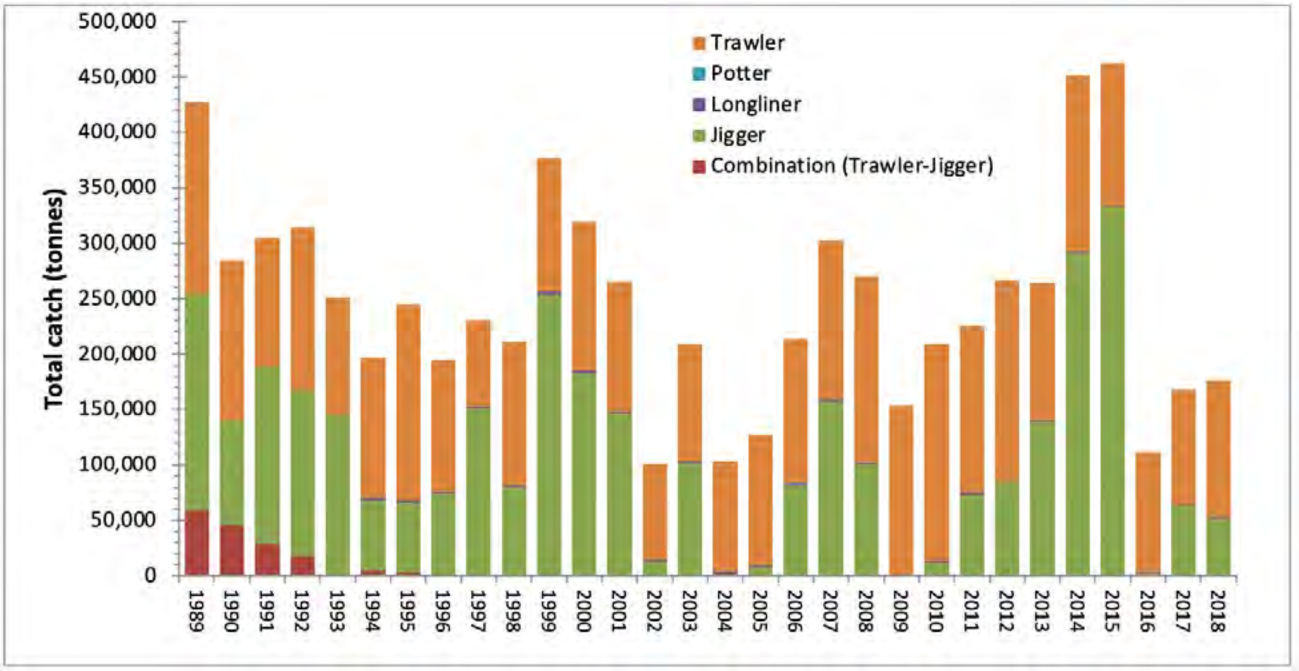

Fig. 4.8: *Total annual catch by vessel type, based on Table C.1 in [11].*

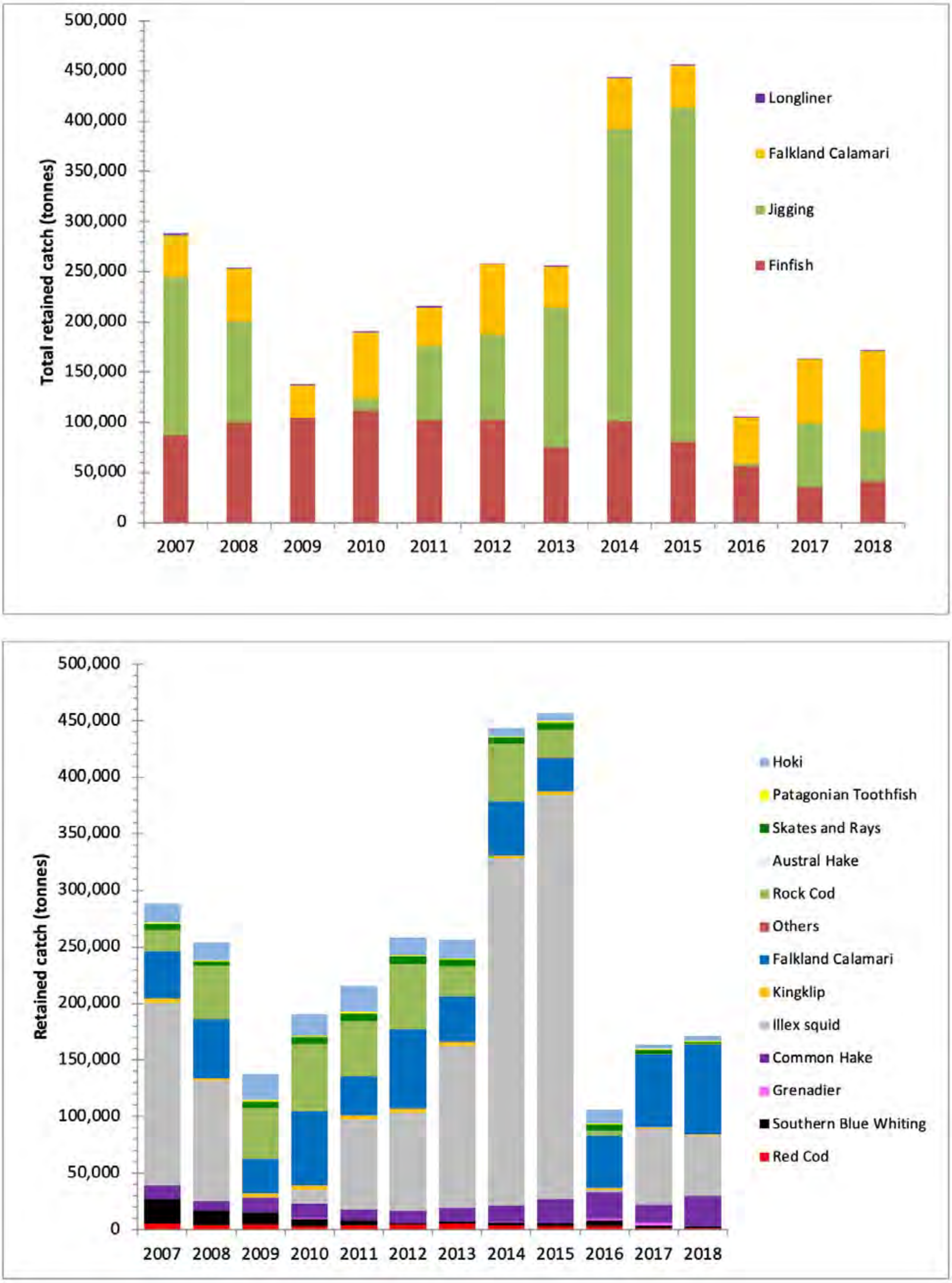

Fig. 4.9: *Catches between 2007 and 2018 by a) broad gear/vessel type and b) species. In a) trawl is divided by main target species – Falkland Calamari (Doryteuthis gahi) and fin-fish (a mix of fin-fish and ray and skate targeted fisheries). Scientific names for species in (b) are provided in Table 4.2. Data courtesy of FIG Fisheries Department.*

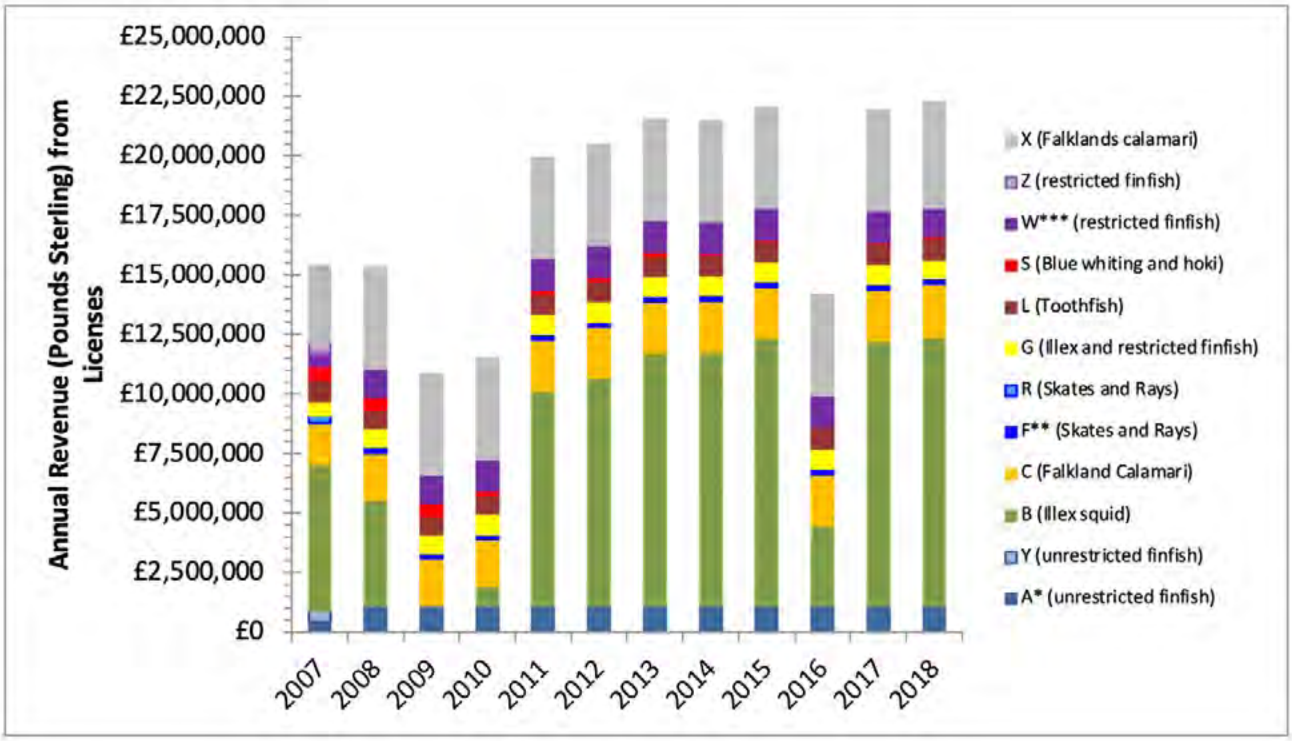

Fig. 4.10: *License fees paid to FIG between 2007 and 2018 by license type, after Table B.13. in [11]; * A+Y since 2008, ** F+R since 2008, and *** W+Z since 2008.*

Most of the annual catch is exported; the fishing industry depends almost entirely on export revenue [2]. Export revenues themselves are determined by a mix of quantity and composition of catches, international market price for different fish – the Falkland Islands almost certainly being a price- taker for most fish products – and foreign exchange rates. Euro to Great British Pound (GBP), and therefore the equal value Falklands Pound, exchange rates have a significant effect on revenue as a good deal of fish export is destined for Spain, and the devaluation of the GBP against the Euro post- Brexit vote has had a positive impact on revenue [2]. Although, it is probably worth noting that as oil is priced in US Dollars, devaluation of the GBP against the US Dollar would mean higher local fuel costs (in GBP equivalent), which coupled with a general increase in the price of oil over the 2016 to 2019 period is likely to have passed extra fuel costs to industry in FKP terms, for those vessels that refuel in the Falkland Islands.

Table 4.3. Fishing type categories used in the fisheries analyses, corresponding categories of Falkland Islands fishing licenses and a short description.

Broad Fishing Category	Corresponding Licenses	Description
Jigging	B	Jigging for *Illex* and *Martialia* squid
Loligo or Falkland Calamari	C & X	Fishing for *Doryteuthis gahi* squid
Finfish	A,G,W, F & S	Trawling for fin-fish, rays and skates
Longlining	L	Longlining for *Dissostichus eleginoides*
Research	E	Experimental fisheries and scientific research

Fishing and MMAs

Method

In order to determine how fishing activities may overlap with proposed MMAs, average annual commercial fisheries catch was mapped by grid square for the FICZ and FOCZ waters. Retained commercial catch data were provided by the FIG fisheries department in an anonymous and aggregated annual format per grid square by five broad fishing categories, as recommended by the department (see Table 4.3). These data were then processed to calculate the total annual catch (tonnes) per grid square, which was averaged across the time series 2007 to 2018 to yield average annual catch (tonnes) per grid square. To determine how much catch volumes per grid square varied between years, standard deviation in annual catch per grid square between 2007 and 2018 was calculated for each grid square. These values were then mapped onto a fisheries grid map of the Falkland Islands. This was done for all fishing categories combined, as well as by individual fishing category.

As there were large changes in catch volumes between some years, especially due to large changes in *Illex* squid catches, an effort was made to standardize for these bumper years: for each year the percentage that each grid square contributed to that year's total catch was calculated and this was averaged for the time series. To illustrate, if 50 tons was hypothetically caught in grid square X in 2007 and the total catch for all fisheries in the entire Falklands Conservation Zones (FCZ: FICZ and FOCZ together) that year was 1000 tons, then grid square X contributed 50/1000*100 = 5% to all fish caught in Falkland waters in 2007. The percentage contribution of grid square X to total annual catch was similarly calculated for each year in the entire time series (2007-2018). This was averaged over the period to yield grid square X's average percentage contribution to total annual catch. This was done for all grid squares. These values are then mapped onto the fisheries grid (used by the FIG Fisheries Department) as average proportional contribution to total catch per grid square. In other words, a map that demonstrates which grid squares were relatively important or not within years was created. This was done for all fisheries catch combined as well as for individual fishing types [12].

To estimate the catch value for the retained commercial catch species, pricing data for fish products exported from the Falkland Islands were extracted from a publicly-available online trade database, TradeMap (http://www.trademap.org/). These databases track prices for exports according to different harmonized system (HS) codes of exported products, including fish products. In brief, price per kg was calculated for each species (weighted by relative export volumes of different product types and HS codes used for the same species), based on total export quantities and values per species per year. Appropriate conversion factors were then used to relate price (in Pounds Sterling) per kg of exported (processed) fish product to retained species weight. The pricing per kg per species could then be multiplied through the respective catches by species to calculate the total value of catch within each grid square. Grid square catch value data were then treated as for catch data above in order to map average annual catch value (in Pounds Sterling) to the fisheries grid for all fisheries combined or individual fisheries. Taking into account sensitivity around financial data, average annual catch value was mapped as a relative percentage, rather than as a gross value. That is, total value for all grid squares combined was calculated, and the average proportional (%) contribution of each grid square was calculated and then mapped. This shows the relative importance of areas by value.

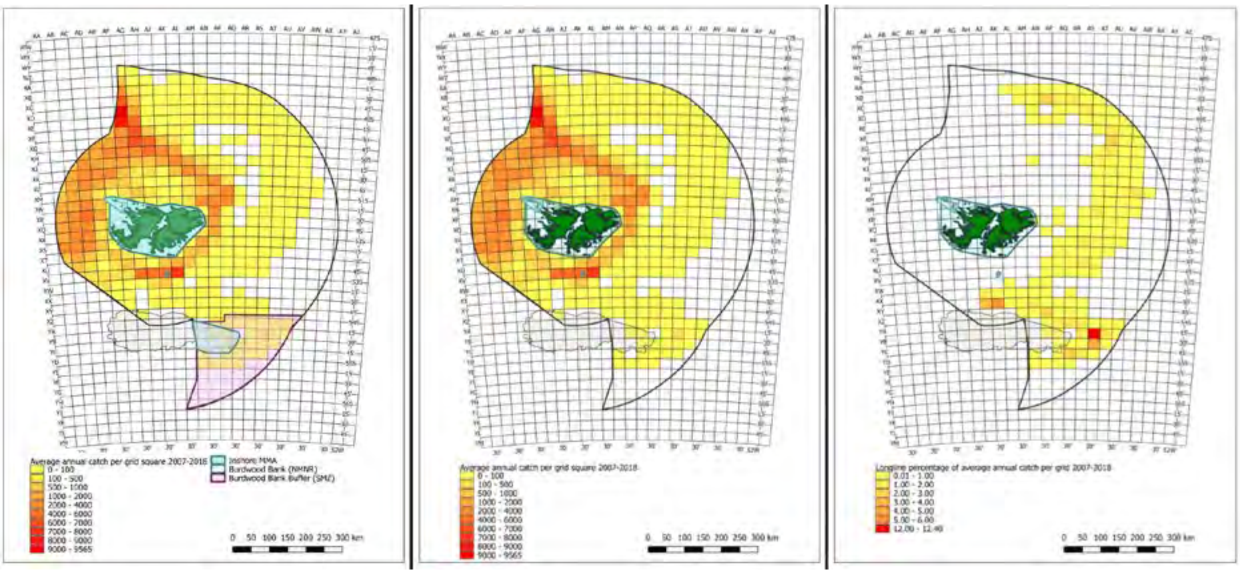

Fig. 4.11: *a) Proposed MMA designs and average annual catch (tonnes) per grid square for all fisheries combined b) average annual catch (tonnes) per grid square for all fisheries combined without MMA layer for comparison, and c) average annual proportional contribution of grid squares to the longline fishery total annual catch, all for the time series of 2007 to 2018. All three of the proposed offshore MMA design options on the Burdwood Bank overlap with catches in the longline fishery. Data courtesy of FIG Fisheries Department.*

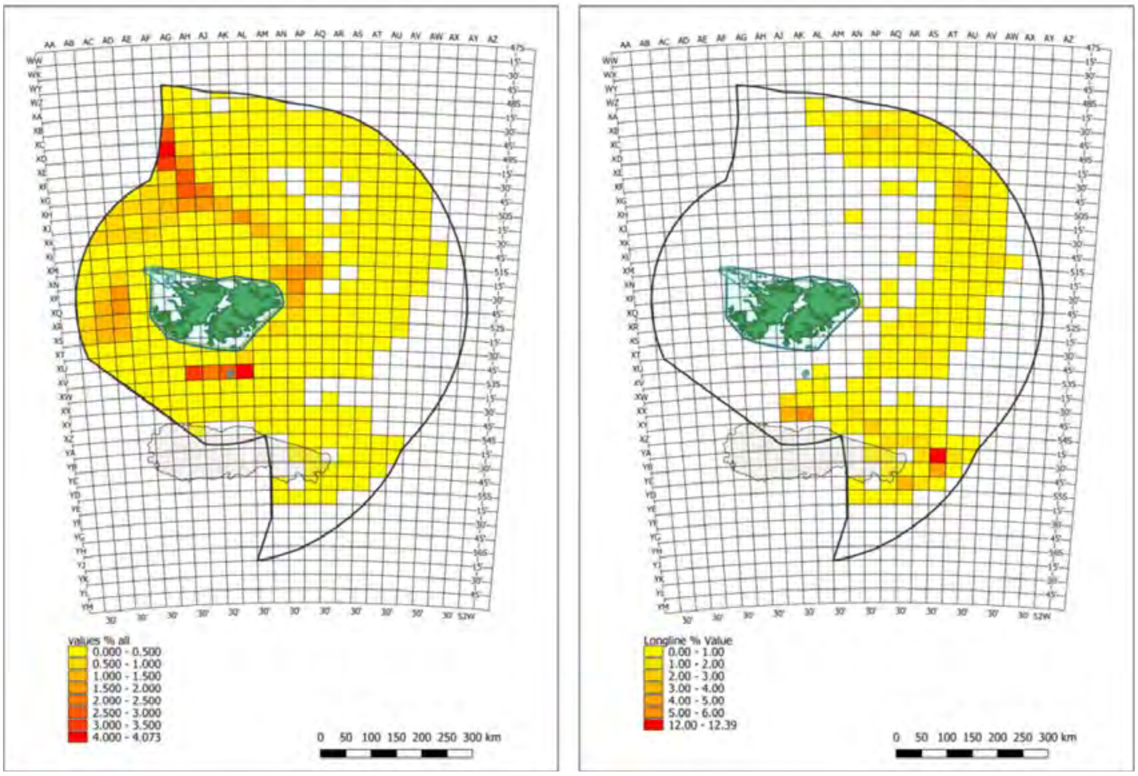

Fig. 4.12: *The proportional (%) contribution each grid square makes to average annual catch value of the entire FCZ for a) all fisheries combined, and b) longline. It is evident that the area around the Burdwood Bank makes a contribution to total catch value for all fisheries and is especially important for the longline fishery. Data courtesy of FIG Fisheries Department. Values were estimated based on prices of Falkland Islands exports available on Trademap.org.*

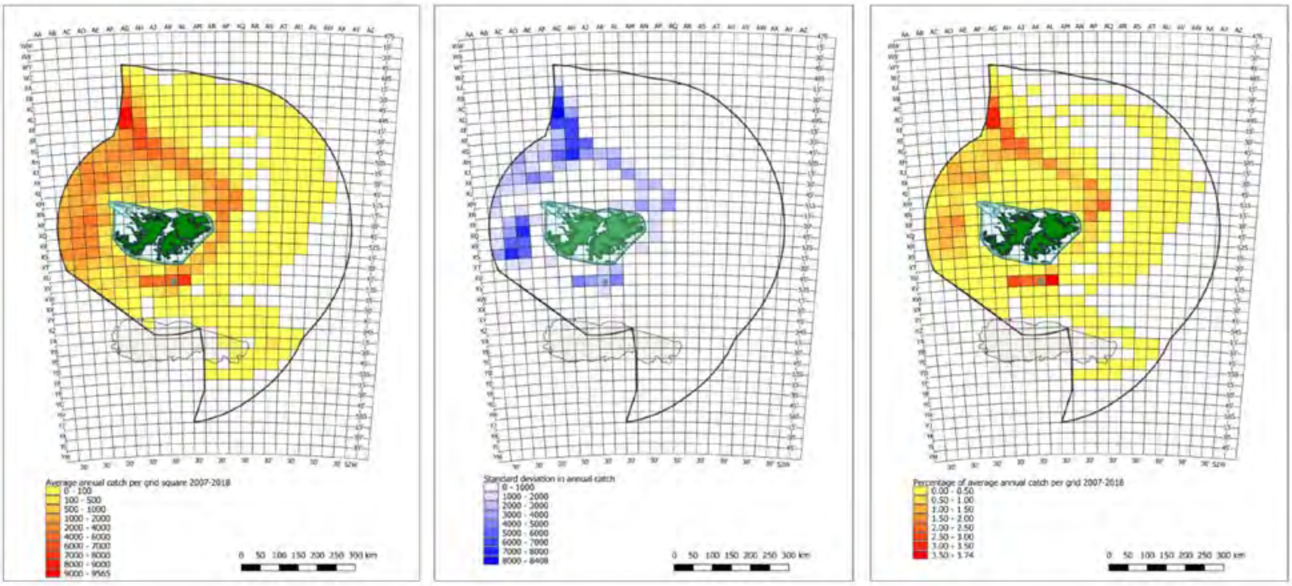

Fig. 4.13: *a) Average annual catch per grid square for all fisheries combined b) standard deviation of catches per grid square between years for all fisheries combined and c) the average percentage contribution that each grid square makes to the total annual catch for the time series 2007 to 2018. The percentage contribution values in (c) help to remove the effect of high catch years, which are usually caused by booms in Illex catches, by showing which grid squares are consistently important across years. Data courtesy of FIG Fisheries Department.*

Findings

There is no overlap between current offshore commercial fisheries catches and the proposed National Marine Nature Reserve (NMNR) around Beauchêne Island or the proposed inshore MMAs (except the Jason Islands NMNR) as fishing permit conditions stipulate that vessels cannot fish closer than 3 nautical miles from the baseline from which the Falkland Islands territorial sea is measured [13]. The NMNR around the Jason Islands extends slightly beyond the current Fishing Closure Areas; this area is very small, and overlaps the edges of four grid squares. However, the proposed Burdwood Bank MMA designs overlap with areas that are commercially fished in the longline fishery (Fig. 4.11). The effect of proportional contribution to overall economic value of fisheries is similar, with areas around the Burdwood Bank making a contribution to the total annual value of catch across the entire FCZ (Fig. 4.12). It's worth noting, that longlining does not currently take place at depths shallower than 600 m, according to permitting conditions of fishing licenses, so that overlap with the NMNR proposed for the Burdwood Bank itself should not take place as the boundary of this NMNR approximately corresponds to the 200 m isobath. Some fishing catches are recorded in grid squares lying over the Bank because of the mid-day GPS location of vessels, though fishing is not actually taking place there. Or in some cases, fishing may be taking place in only the part of the grid squares below 600 m depths. The proposed Burdwood Bank Buffer Sustainable Multi-use Zone MMA, which surrounds the Burdwood Bank at greater depths, does overlap with longline fishing activity.

Apart from longlining no other fishery currently overlaps with the MMAs proposed for the Burdwood Bank area. In the 1990's there was some fishing for rock cod on the Burdwood Bank, but it seems unlikely that this would ever happen again, because there are already a number of restrictions in place on the Burdwood Bank.

It should also be noted that different fishing licenses only allow fishing in certain areas and restrict fishing in others (i.e. there are currently areas closed to certain kinds of fishing – see license blocks in Fig. 4.7, as well as seasonal closures – not depicted), and this also affects the geographical spread of catch volumes.

During consultation the fishing industry body, Falkland Islands Fishing Companies Association (FIFCA), suggested that grid squares that were lesser-used in the past will not necessarily continue to be lesser-used in the future and if species distributions or target-species were to change, areas that are not currently much fished may become more valuable fishing grounds. Though, any shift in fishing activity into other grid-squares would also obviously depend on geographical license restrictions and other fisheries management conditions. Looking at variation between years from past time series, shown as standard deviation (Fig. 4.13), it appears that those grid-squares with the highest average catch were the most variable, meaning that the high catches in them took place in only some years, while unused or low-productivity grid squares appear to show little variation, having more consistent catches between years.

Apart from the activities already described, no further offshore commercial fishing activities are officially scheduled to commence. There have previously been discussions around an offshore Grenadier (Macrouridae) fishery in the FCZ. The FIG fisheries department confirmed that if a Grenadier fishery were to happen in future it could be as large as 3000 tonnes, but it would take place outside the 3 nm limit from the coast and probably be at depths shallower than 600 m, putting it north of any of the proposed MMAs on the Burdwood Bank in Fig. 4.2. In short, if this fishery were ever to go ahead, it seems unlikely to overlap with any of the currently proposed MMAs.

In terms of the inshore MMAs, no large-scale commercial ventures are currently being undertaken in the inshore (< 3 nm from the baseline) waters and offshore commercial fisheries are restricted from fishing within 3 nm of the baseline by their license conditions [13]; no large-scale commercial fisheries overlap with the inshore MMAs (except with a small edge of the Jason Islands NMNR, as described above). However, a few smaller-scale fisheries have taken place within the confines of the inshore MMAs in recent decades.

Commercial trials for snow crab (*Paralomis granulosa*) fisheries were conducted as early as 1986 [14], though the snow crab license was reported to have been rarely used in 2018 with total catch less than 1 tonne [11]. During the 1980's and 90's it operated as a commercial fishery, mainly near East Cove, but in subsequent years it diminished in size to an artisanal fishery that only supplied small quantities to the domestic market.

An experimental, small-scale beach seine fishery for Falklands mullet (*Eleginops maclovinus*) has existed since October 2000 [14]; it was reported as a minor commercial fishery in 2018 only producing a modest supply to the domestic market [11]. This fishery has mainly taken place in accessible coastal areas between Stanley and Goose Green, though recreational fishing for mullet (mainly rod and line) takes place on-shore throughout the islands. Recreational catches are likely to be small given the size of the Falkland Island population.

An inshore Patagonian scallop (*Zygochlamys patagonica*) directed fishery also existed between 2002 and 2006, that was largely experimental, but any catch of this species after 2006 has been as bycatch in other fisheries; indeed no scallop-directed fishery took place in 2018 and only 4 tonnes were taken as bycatch in other fisheries [11], [14]. If any scallop fishery were to happen in future it seems unlikely that it would be [licensed] within 3 nm of the coast, as coming inshore of the 3 nm limit was part of the reason for beaching of the scallop fishing vessel in the past.

Apart from the above, there has not previously been any other semi-commercial or commercial fishery in the Falklands' inshore waters. A study of potential inshore fisheries (species) was made in 2016 alongside an economic feasibility study [14;15]. A variety of different species were assessed, including limpets, octopus, mussels, barnacles, squid and sea- urchins. The study determined that many of the species were data limited and further studies would be required before any conclusions could be drawn on the viability and sustainability of fisheries for the assessed species from a biological perspective, such as how they might respond to exploitation [14].

From the economic analysis [15], of the twelve candidate species that were assessed, Patagonian scallops and mussels were found to have the most interest for cruise ship and Falkland Islands domestic market, while southern giant barnacle and Chilean red sea urchin were thought to have the most potential for export. However, the cruise ship and domestic markets were found to be small and only capable of supporting part-time artisanal activity with a low economic benefit; from the perspective of import substitution, crustaceans, molluscs and other aquatic invertebrate imports to the Falkland Islands totalled only £6,500 in 2012 [15]. Food safety testing costs created a barrier to entry for export market and were thought to lower viability of operations at low production volumes. For anything beyond a one or two person business operation, it was thought that the export market would need to be tapped and that this would require much larger production volumes; volumes which were likely to only be realized with aquacultural production [15]. In summary, the inshore fisheries market study painted a generally unfavourable economic view of any commercial inshore fisheries for the twelve candidate species beyond the artisanal scale, although it suggested that multi-species aquaculture could have provided an alternative means of production for these species with a lower ecological impact and a potentially higher production volume and better financial outlook than harvesting [15].

2. OIL, GAS AND MINERALS

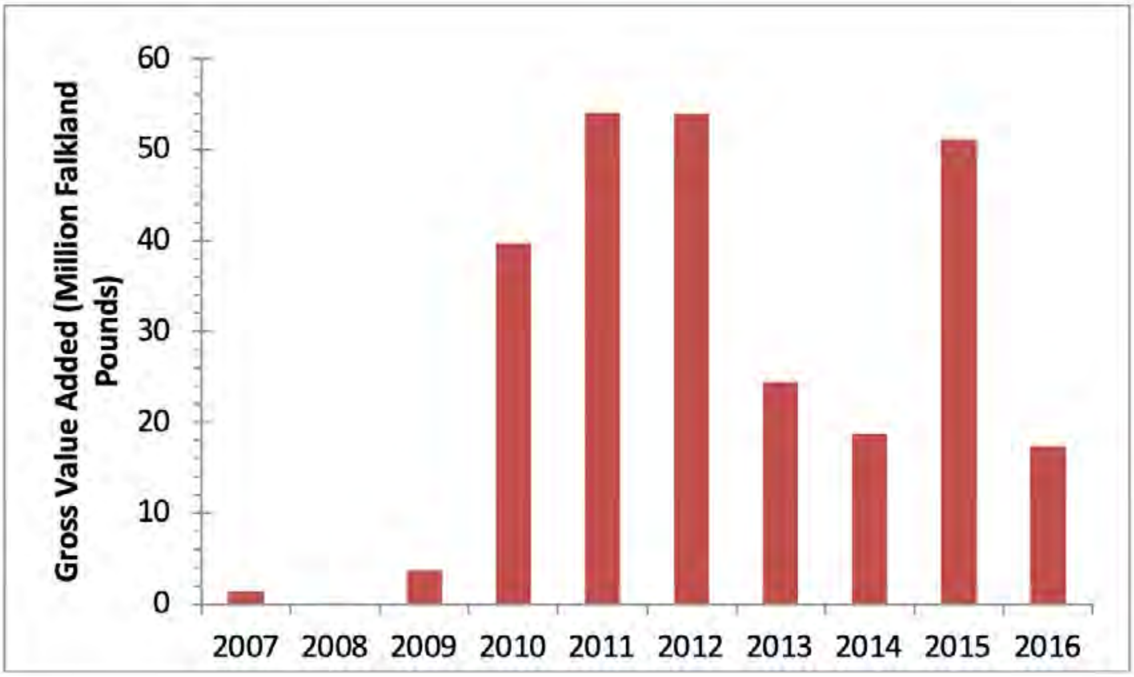

Fig. 4.14: *The Gross Value Added of oil and gas related activities in the Falkland Islands, constant 2012 prices, after Fig. 23 in the FI State of the Economy Report 2018 [2].*

The Falkland Islands is currently in the exploration phase of offshore hydrocarbons. This exploration has stimulated the economy and generated revenue to government [2], contributing significantly to the Islands' GVA (see Fig. 4 above and Fig. 14). Should oil production go ahead – a decision which companies are likely to base on the appeal of a specific project, expectations of future oil price and other factors, and pending government approval – an even greater impact is anticipated [2].

As of 2016, 14 Falkland Islands residents, or 0.8%, were employed in *mining and quarrying, including oil and gas exploration* activities (Fig. 4.6, above). This Fig. seems small, but it is because Falkland Islands economy imports workers as well as services, e.g. engineering, technical expertise, services related to oil exploration, for specialist tasks and so non-residents perform a good-deal of the labour, especially in the fishing and oil and gas industries [2].

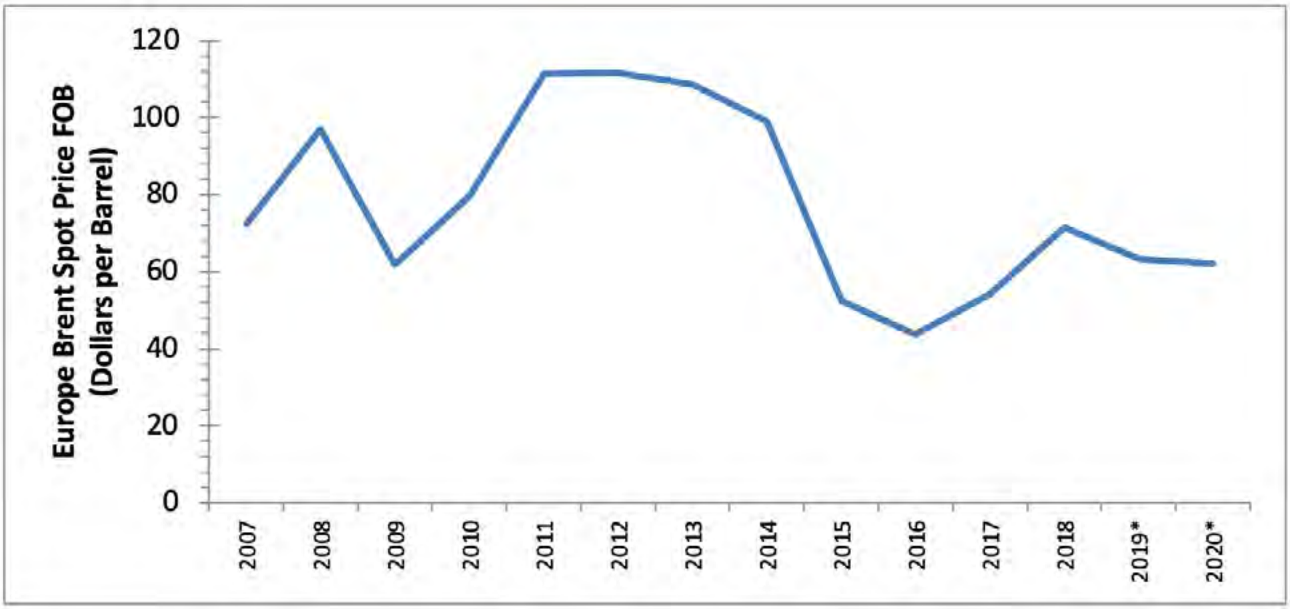

Fig. 4.15: *Brent crude oil prices, from US Energy Information Administration in September 2019 (https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRTE&f=A and https://www.eia.gov/outlooks/steo/marketreview/crude.php); *note that 2019 prices are not based on a full year and 2020 is projected future price.*

Table 4.4. Acreage rentals of production licenses, taken from the FIG Department of Mineral Resources website (http://www.fig.gov.fk/minerals/regulatory/fiscal-regime/21-licensing/66-acreage-rentals) on 20 August 2019. Please note that greater detail is provided on the website with thorough explanation and the information below is merely an extract of that for illustrative purposes.

License phase	Rent
Licenses awarded in 1996	
Phase 1 (Years 1 through 12, or for as long as the extended Phase 1 lasts beyond 12 years)	US$30 per km^2 per annum
Phase 2 (seven years following on from the end of the extended Phase 1)	US$60 per km^2 per annum
Phase 3	US$600 per km^2 per annum
During development	US$375,000 per development area
Licenses awarded since 2001	
Phase 1 (of 3 to 5 years depending on work programme)	US$30,000 per annum for first licence held, plus US$10,000 for each additional licence
Phase 2	Fees as per Phase 1
Discovery area	US$375,000 per annum per discovery area
Field production	US$375,000 per annum per square kilometre of a production field.

Current oil and gas exploration activities take place in the Designated Area within the Falkland Islands Conservation Zones under various production licenses. Acreage rentals from these licenses (Table 4.4), as well as corporation tax, and possibly feed-on effects on other industries related to companies' current (exploratory) activities in the Falkland Islands contribute to the local economy. In addition to revenue from the variable acreage rentals [16], the Falklands fiscal system comprises a 9% royalty on production (the market value of any petroleum won), although this can be adjusted at the discretion of the Falkland Islands Governor, and 26% corporation tax on adjusted chargeable profits [17]. This is a brief description of total government charges, but full details may be found on the website of the FIG Directorate of Mineral Resources [17].

A report on the socio-economic impact of the oil industry from the FIG Policy and Economic Development Unit is expected to be produced towards the end of 2019, which will update earlier studies.

An earlier socio-economic study of oil and gas development in the Falkland Islands was published in 2013. This study anticipated that development of the Sea Lion field by Premier oil and related activities would create up to 550 short to medium term onshore jobs between 2014 and 2017, and 170 support jobs onshore and 125 offshore jobs in the longer term, as well as have substantial impacts on Falkland Islands GDP and FIG revenues [18]. However, oil production has not yet begun and these employment numbers are not yet realized, although exploration activities have contributed to Falkland Islands GVA and produced tax revenue, as described above. The Director of Mineral Resources at FIG pointed out that the socio-economic study of oil and gas development in the Falklands [18] is now somewhat outdated because of international oil price shifts and changes to the expected scope of projects in the near term. The upcoming study by the FIG Policy and Economic Development Unit will update it to more accurately depict the current industry; the economic impacts will likely be less than the 2013 report predicted because of the reduction in the number of jobs and infrastructure needed on the Falkland Islands as a result of reconfiguring the development projects to improve project economics at lower oil prices. Most of the benefits to the Islands will be received in the form of taxation and royalties; royalties become active on commencement of commercial production and corporation tax is payable on company profits.

Apart from the offshore oil and gas exploration activities, the FIG Directorate of Mineral Resources has indicated that there has been no offshore mining activity in the Falkland Islands and that it seems unlikely that there will be any such activity in the foreseeable future. The low likelihood of any future mineral resource extraction at sea, apart from hydrocarbons, is based on surveys done of the seafloor, unfavourable weather conditions in the region and the great depths of the seafloor, which make any extraction difficult.

The Oil Industry and MMAs

The Department of Mineral Resources at FIG is the regulatory body that oversees the offshore oil and gas industry, as well as being responsible for overseeing any onshore mining and mineral exploration [19]. The different types of licenses are fully explained on the FIG Department of Mineral Resources website; [20] and [21] should be consulted for a detailed explanation. Essentially, though, exploration licenses allow for seismic and benthic-survey type exploration only, while production licenses allow for some extraction to test wells, give right to exclusivity and eventually allow for commercial extraction, pending approval. Approval for commercial production is a separate and extensive process that takes place prior to the production license entering a commercial extraction phase. For the open-door licenses (those issued since 2001), once approval has been granted for commercial extraction the production license moves into a commercial production phase (also called the 'exploitation phase') with 35 years of extraction rights. This is then ultimately followed by a decommissioning phase.

None of the currently issued licenses (Fig. 4.16) overlap with the areas proposed as MMAs in Fig. 4.2. However, some license blocks lie just to the north of the proposed MMAs on the Burdwood Bank, and as such, the oil and gas sector is considered in this chapter.

The Department of Mineral Resources stated that the current oil license blocks are about as close to the MMAs as oil license blocks are likely to get in the foreseeable future. This statement is based on the proposed locations of the offshore MMAs around the Burdwood Bank (the Burdwood Bank NMNR and the Burdwood Bank Buffer SMZ; Fig. 4.2) and the structure of the seabed in this area – depths, seabed composition etc. – which affect placement of favourable sites for oil production. For example, the parts of the FCZ near the south of the Burdwood Bank and to its east are at great depths and in very rough seas, making exploration for oil in these regions highly unlikely, at least in the foreseeable future. It is also based on the fact that most inshore activity related to oil is going to be centred around the Islands' port areas: Stanley, Port William, Berkeley Sound and/or MARE harbour and there are currently no plans to bring any oil or gas inshore.

The main oil industry development is currently focused around the Sea Lion fields in the North of the FCZ (away from any proposed MMAs), and in the near future the majority of industrial activity is anticipated to be around this region. It should be evident by the end of 2019 whether commercial extraction will begin in the Sea Lion Field. In the case of a positive decision, it would be approximately three and a half years prior to commercial extraction of oil beginning. Following this, there will be increased onshore and offshore activity, e.g., rig set-up, equipment brought in (some via the Falkland Islands), and associated economic activity. Once this kind of project is up and running it is likely to increase development of the industry further, with other fields becoming active.

In the inshore, there is currently only light infrastructure in Stanley: Premier oil has leased the Temporary Dock Facility (TDF; Fig. 4.17) just to the east of FIPASS (the Falklands Interim Port and Storage System). The TDF is intended to be the support port for the offshore oil industry. Berkeley Sound, one of the Falkland Islands Port areas, is intended to be used for standard maritime activities. At one stage it was envisioned for ship-to-ship transfer of oil, but that is no longer the case as oil transfer will now be done at sea. Instead, Berkeley Sound is anticipated be used for more general shipping and transport purposes, such as offloading or transfer of equipment.

The temporary storage of heavy anchor chains used for oil rigs is the only activity anticipated in the inshore area to take place outside of harbour areas, and therefore overlap with the Inshore SMZ. It is generally considered unsafe or undesirable to store these chains in harbour areas as they are large and heavy and can get tangled with anchors from general shipping. The chains – excess from the lengths used by the rigs – are very large and are heavy and therefore need to be laid flat on the seabed to be securely stored. Due to their weight, they tend not to move around. They are usually stored for a few months at a time, and then retrieved from the site. Chains need to be stored inshore where they won't be subjected to heavy currents and where it's shallower for ease of storage and removal; they are very bulky and extremely difficult to store on land, necessitating the use of the seafloor. However, chain storage is a low probability requirement for the industry.

In summary, there should not be direct spatial overlap with the oil and gas industry and MMAs, apart from accessing areas zoned as Ports and for inshore chain storage in the Inshore SMZ.

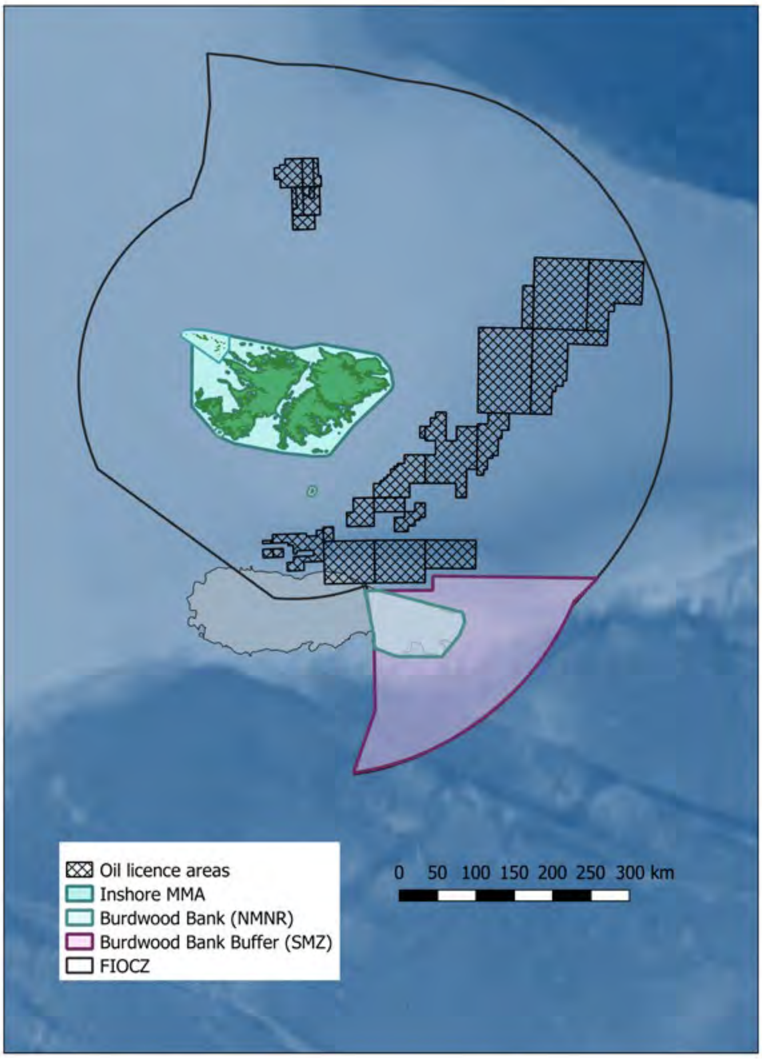

Fig. 4.16: *Map of the Falkland Islands Interim and Outer Conservation Zones indicating oil license blocks and the proposed Marine Management Areas (MMAs). Full details of oil license blocks may be found on the latest Falkland Islands: Offshore Exploration Areas Map on the Mineral Resources Website (http://www.fig.gov.fk/minerals/component/jdownloads/send/21-misc/134-emailable-a4-map).*

Fig. 4.17: *Photo of the Oil Industry's Temporary Docking Facility (TDF) leased by Premier Oil. FIPASS is pictured in the background.*

3. TOURISM

Tourism, the provision of facilities and services to tourists, such as accommodation and food, accounted for 1.3% of GDP in 2016 [2], with a gross value added of FKP£3.8 million in 2016 [22] and £2.9 million, 1.7% of GDP, in 2014 [9]. In terms of employment, 89 people, or 4.9% (Fig. 4.6, above), cited tourism as their primary employment in the 2016 census, and a further 96 recorded secondary employment in the sector [2].

The Falkland Islands receives different types of tourism. Tourists may come by air through flights landing from the United Kingdom, Chile, and, from November 2019, from Brazil, or by ship. The Falkland Islands Tourist Board considers tourists, frequently termed 'land-based tourists', to be non- residents who travel to the Falkland Islands for between one night and a year for purposes of transit, visiting friends and family, leisure activities or business. Day-visitor tourists on the other hand typically spend just one day and no nights in the Islands and, as they mostly arrive on the many cruise ships that pass through the Islands and typically in the summer between October and April, this is often referred to as 'Cruise Tourism' [3].

In the 2018/19 season there were 5,565 land-based tourists, of which 1,903 visited the Islands for leisure, and 62,505 cruise day visitors. On average land-based, leisure tourists stayed 10.4 nights in the Islands and spent FKP£214.09 per night, equivalent to a total of £4.2 million spent over the period, while day visitors spent an average of FKP£64.89 per day, equivalent to a total spend of £4.1 million over the season [3].

Tourism has been growing on the Falkland Islands. There were 5,656 land-based tourists in 2018 compared to 3,448 in 2000, an increase of 64%. Of this, the number of tourists coming for leisure increased by 47 % from 1,291 in 2000 to 1,903 in 2018 [3]. Analyzing data kindly provided by Falkland Islands Department of Customs and Immigration, it can be seen that the number of cruise ship passengers arriving in Stanley, Falkland Islands increased from 22,125 in the 2000/01 summer season to 62,505 in the 2018/19 summer (Fig. 4.18). There was a significant dip in tourist and vessel numbers from 2008 to 2013, suggested to be as a result of the economic crisis [2], but numbers have subsequently recovered and appear to be on an upward trend. Vessel numbers have collectively mirrored this trend. Average vessel size has increased between 2000/01 and 2018/19, with increasing numbers of vessels in larger size classes (50 000 – 79 999 and >80 000 NRT) in recent years.

In addition to supporting jobs and businesses, these cruise ship day-visitors also bring in government revenue in the form of a passenger levy, as well as other vessel-related duties (see also section 5 Harbours, Shipping and Ferry). A levy is charged per passenger aboard the vessel (Table 4.5); a different fee applies if passengers visit Stanley only or Camp and Stanley together. The lower fee for the Camp and Stanley combined is applied to encourage tourism in Camp. Total passenger levies collected have increased since 2012/13 to FKP£1,365,872 in 2018/19 (Fig. 4.19). Some revenues are lost due to cruise trip cancellations (Fig.4.20). The main reason for cancellation, where the reason was known and recorded, was unfavourable weather (Fig. 4.21).

Vessel trips can be reduced if weather is poor, due to there not being a site for cruise vessels themselves to dock, and the use of smaller craft to ferry passengers in poor conditions is not popular due to rough seas.

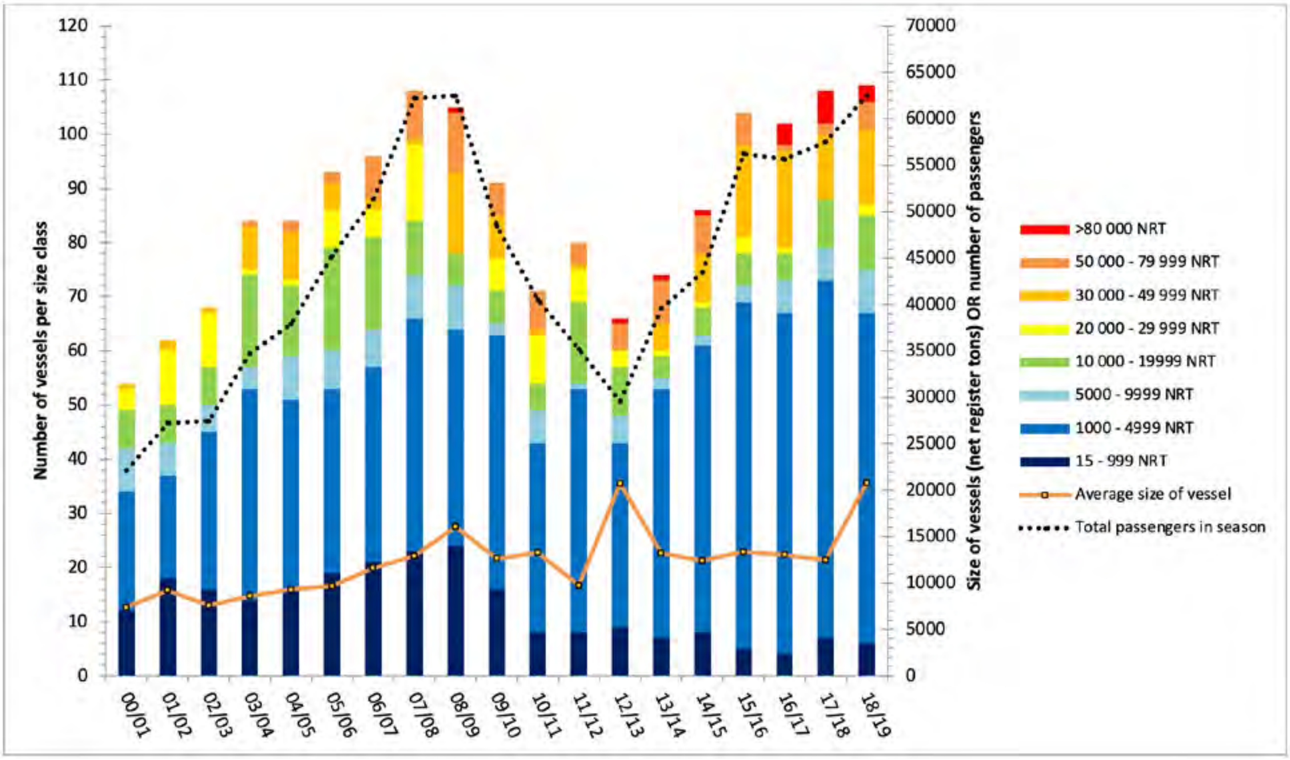

Fig. 4.18: *The total number of cruise ship passengers arriving per season to Stanley, Falkland Islands between 2000 and 2019, as well as the number of vessels in different size –net register tons (NRT) – classes, and the average size of vessels (NRT). Data courtesy of the Falkland Islands Government Customs and Immigration Service.*

Table 4.5. Passenger Levy (per passenger aboard) applied from that financial year onwards until subsequent fee change. Data courtesy of the Falkland Islands Government Customs and Immigration Service.

Financial Year	Stanley Visit Only	Stanley & Camp Location Visit
04/05	£15.00	--
05/06	£15.00	£5.00
07/08	£16.50	£5.50
09/10	£18.00	£6.00
15/16	£20.00	£7.00
16/17	£21.00	£7.50
18/19	£25.00	£7.50
19/20	£26.00	£7.50

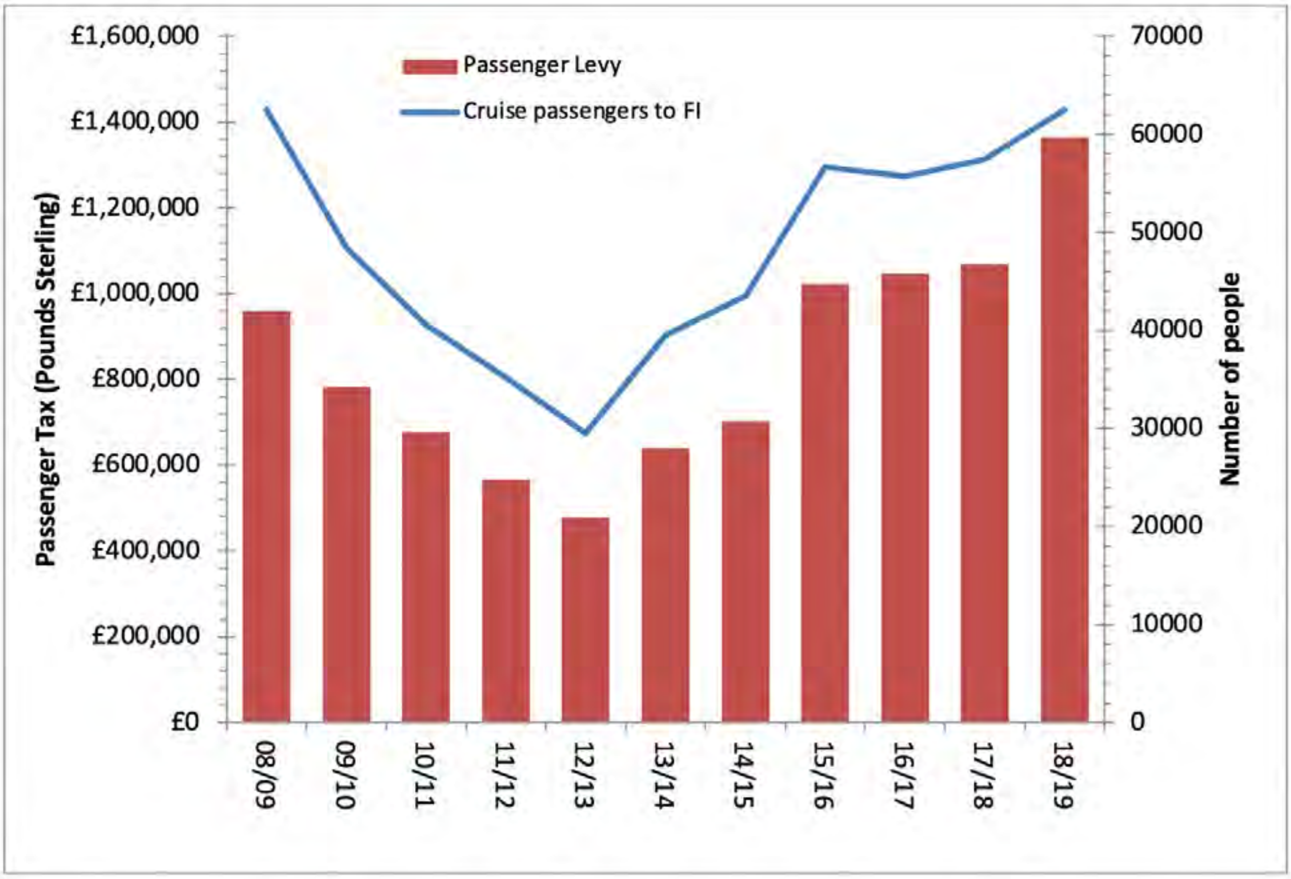

Fig. 4.19: *The total number of cruise ship passengers arriving per season to Stanley, Falkland Islands between 2000 and 2019, as well as the number of vessels in different size –net register tons (NRT) – classes, and the average size of vessels (NRT). Data courtesy of the Falkland Islands Government Customs and Immigration Service.*

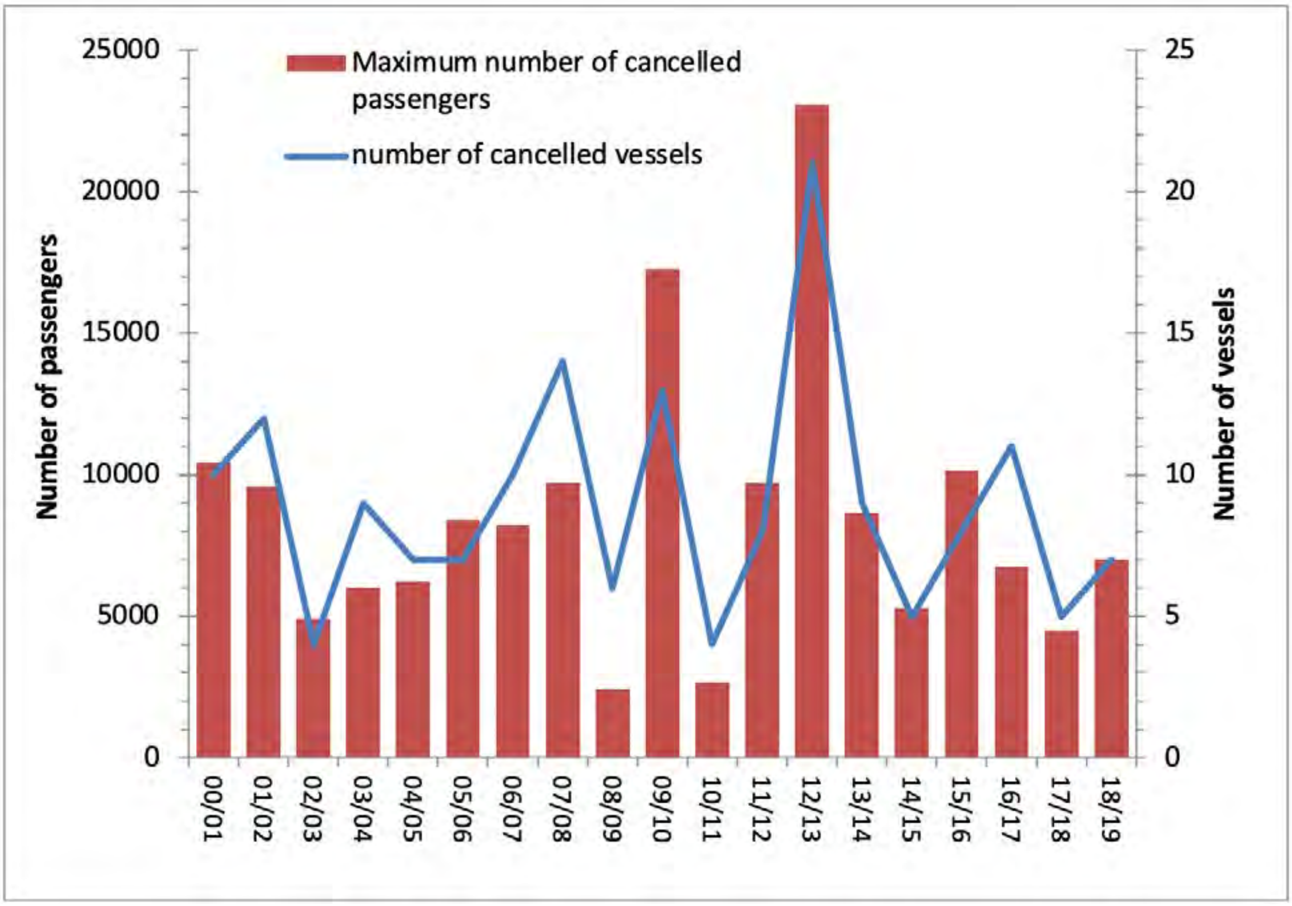

Fig. 4.20: *The number of vessels that cancelled trips to Stanley, Falkland Islands, and the corresponding maximum number of non-arrived passengers. Note that these passenger numbers are based on maximum occupancy of vessels, though vessels are generally not at maximum capacity. FI Tourist Board suggests occupancies of around 80% are on the generous end), so it is likely an overestimate. Data courtesy of FIG Customs and Immigration Department.*

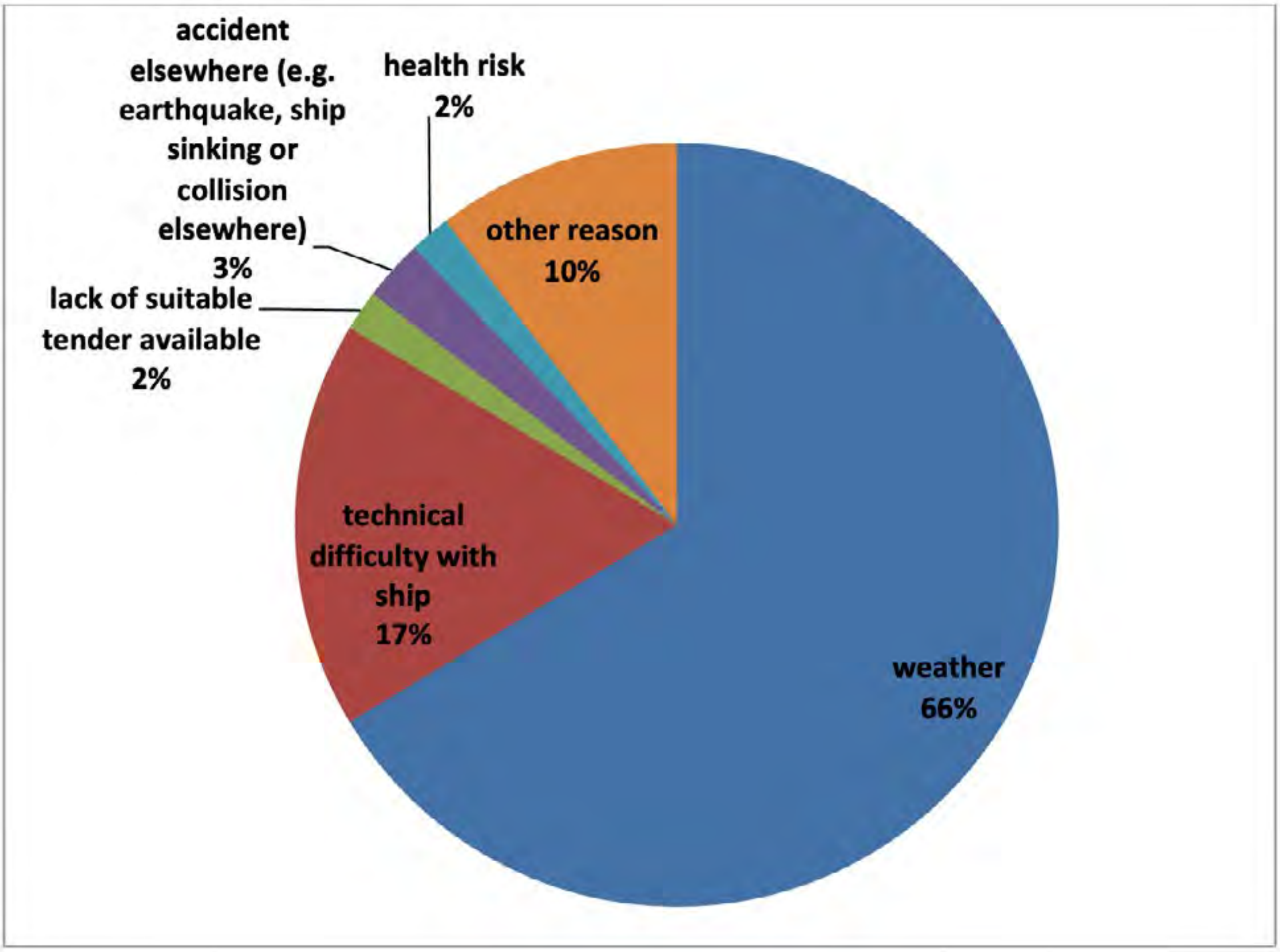

Fig. 4.21: *Different reasons for cancellation of cruise vessel visits to Stanley. Reasons were provided for 116 of 170 cancelled vessel records between 2000/01 and 2018/19. Data courtesy of FIG Customs and Immigration Department.*

Tourism and MMAs

Tourism in the Falkland Islands is largely a land-based activity. However, as many tourists come to the Islands as day visitors on cruise ships, there is a degree of interaction with tourist vessel traffic and the proposed inshore MMAs (Fig. 4.2). Cruise ships primarily land passengers in Stanley port area. However, there has been increasing interest in visits to Camp locations by smaller vessels, typically those carrying less than 600 passengers aboard (Fig. 4.22 and 4.23). Discussions with the Falkland Islands Tourist Board (FITB) indicate that there is some potential for increasing activity at those Camp sites and possibly additional sites in Camp in the medium to long term if Falklands-only or Falklands and South Georgia-only cruise ship itineraries potentially become more popular for expeditionary vessels in the face of cruise vessel crowding in the Antarctic. However, there are currently no confirmed new routes. FITB have indicated that it is unlikely that large vessels (> 500 passengers) will visit Camp.

Additionally, one of the major tourist attractions for the Islands is its wildlife, much of which is coastal and marine, and therefore depends on habitats within the proposed MMA areas. For example, word cloud analyses of tourist surveys pick up words like 'landscape', 'penguins', 'wildlife' and 'scenery' as being fairly important to tourists (e.g., Falkland Islands Tourist Board, 2019, 2018, 2017), suggesting that this is one of the major attractions for them to the Islands.

It is difficult to estimate exactly how important tourism related to the marine environment – i.e. tourism based on coastal walks, penguin and marine mammal sites – is as an income and economic activity for those landholdings in Camp where it occurs. To try to approximate the importance of marine-related tourism for these cases, FIG Policy and Development Unit collected income information for the years 2012 to 2017 to estimate the proportion of total income at a site was due to tourist activities (tours, lodge and self-catering accommodation). These data were aggregated and anonymized by FIG Policy and Development Unit before being provided for analysis in this study.

It should be noted that the following analysis is NOT representative of farms or landholdings throughout the Falkland Islands in general, but only a representative sample of *those landholdings that engaged in marine-related tourist activities.*

Sixteen Camp locations (landholdings) across the Falkland Islands were identified that offered tours, self-catering or lodge accommodation and that also had access to a site of coastal interest (e.g., marine bird or mammal colony or site); i.e., sites in which tourist activities were likely to be primarily driven by activities related to the marine environment. These were classified as being on West Falkland, East Falkland or on the Outer Islands.

For the sample as a whole, tourism contributed an average of 49.44% to the income of individual landholdings considered. It was most important for sites that engaged in marine-tourism on the Outer Islands, where it contributed between 56 and 100% of total income of landholdings and least important on West Falkland, where it contributed only 1 -2 % of landholding income (Fig. 4.24). Those sites studied on East Falkland were more variable with some landholdings getting as little as 5% of their annual income from tourism, while others received all of their income from tourism.

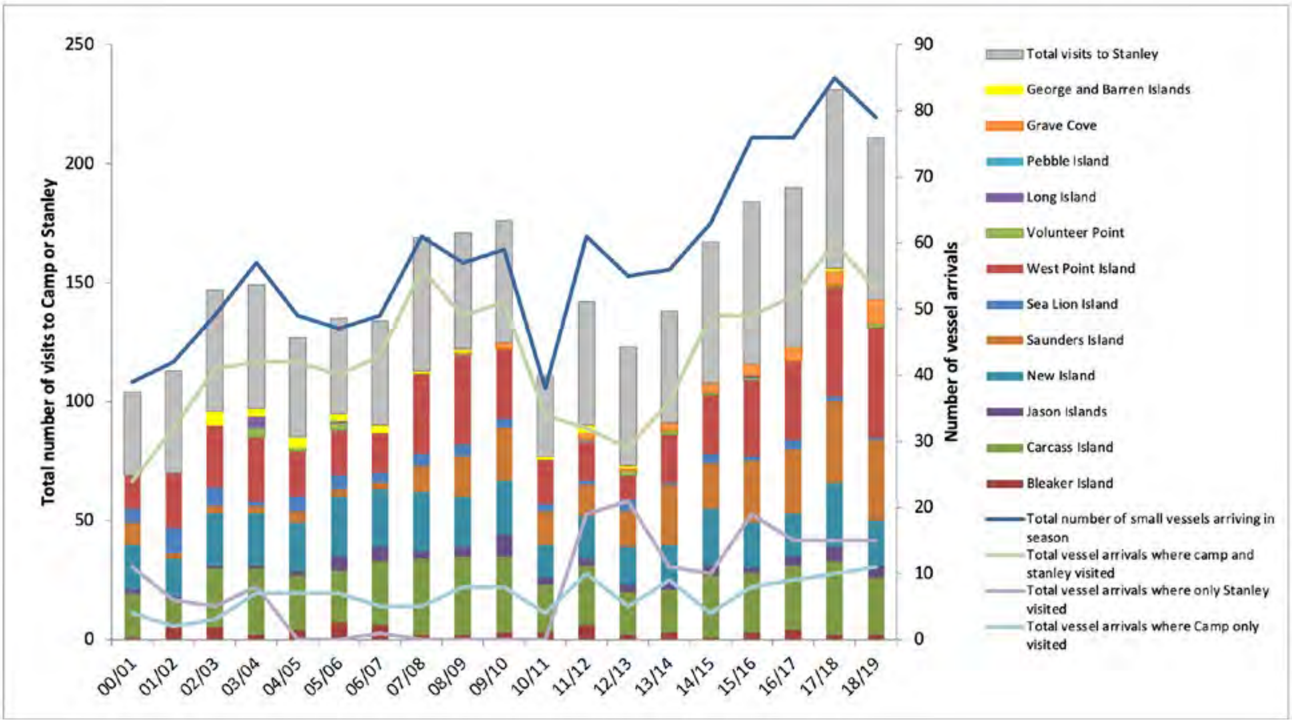

Fig. 4.22: *Number of visits of small cruise vessels (< 600 passengers) to different sites across the Falkland Islands between 2000/01 and 2018/19 (bar graph). There have also been increasing numbers of small vessel (< 600 passengers) visits to the Islands and particularly with itineraries that visit both Camp and Stanley (line graphs). Data courtesy of FIG Customs and Immigration Department.*

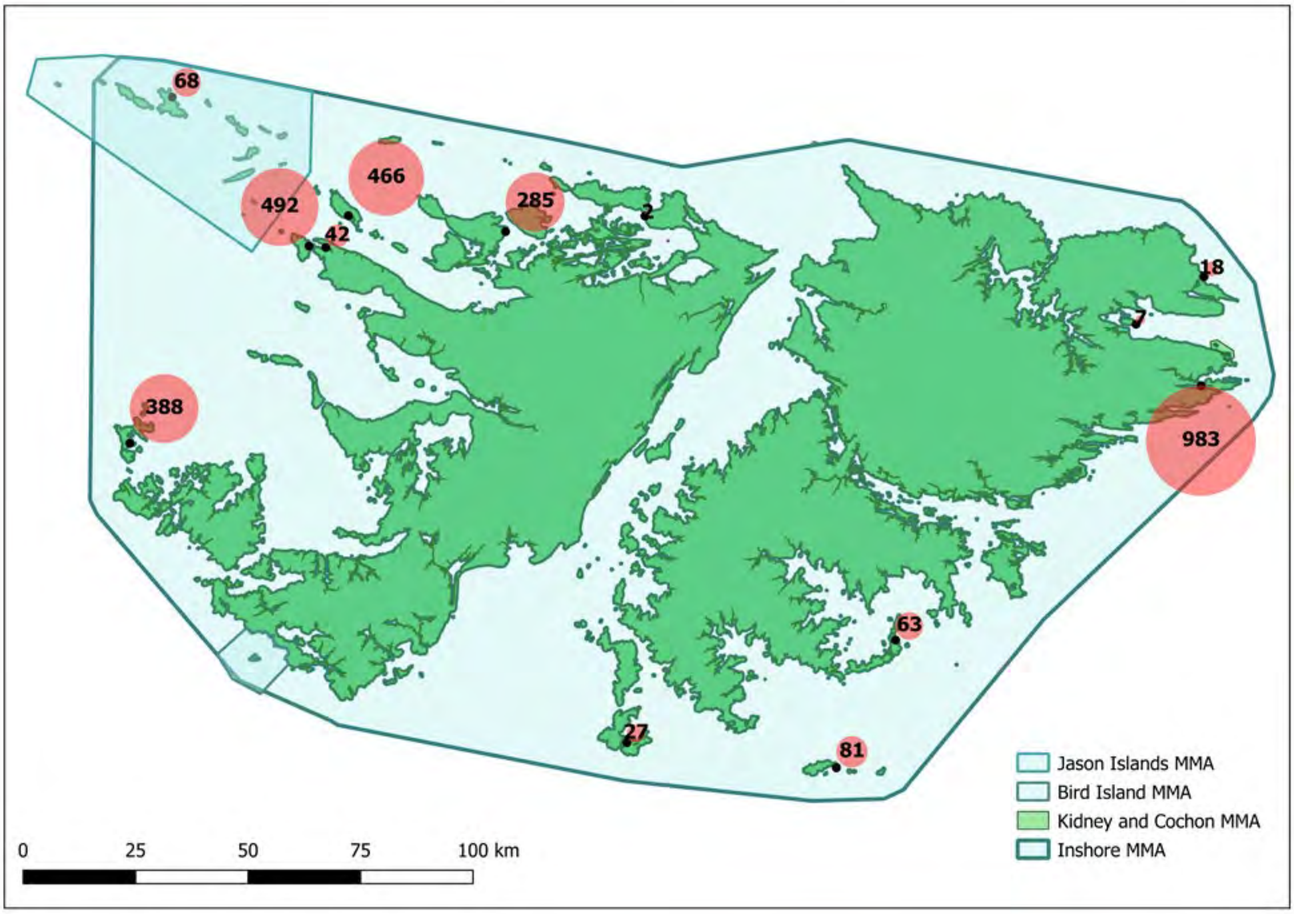

Fig. 4.23: *Map of the Falkland Islands indicating total number of visits (numbers and size of red circles) by small cruise vessels (<600 passengers) per site – indicated by black dot – between 2000/01 and 2018/19. Data courtesy of FIG Customs and Immigration Department.*

The average income from tourism on the sixteen landholdings that engaged in marine-related tourist activities has grown slightly through the period 2012 to 2017 (Fig. 4.25), though the percentage that this contributes to the total income of the individual landholdings has remained fairly stable (Fig. 4.26). In 2016 there was a downturn in the importance of tourism for individual site incomes, probably due to an upturn of wool prices in 2016 resulting in more income from agricultural activities in that year for those landholdings that engage in mixed activities.

Marine-related tourist activities – tours, self-catering and lodge accommodation at landholdings where the main attractions are marine animals and coastal sites – appear to be important for those landholdings that engage in tourist or mixed activities, more so for the Outer Islands and East Falkland. That is, in those areas that are more accessible to land and cruise-based tourism. On West Falkland, such tourist activities are less important, probably due to the inaccessibility of many locations there.

All of the above, information indicates that the tourist sector has been growing throughout the Islands in recent years. This looks set to continue with the Tourism Development Strategy (2016- 2023) aiming for a 49% increase in cruise ship visitors, a 42% increase in tourist expenditure and an 87% increase in the number of nights spent by tourists on the Islands by 2022/23 [2].

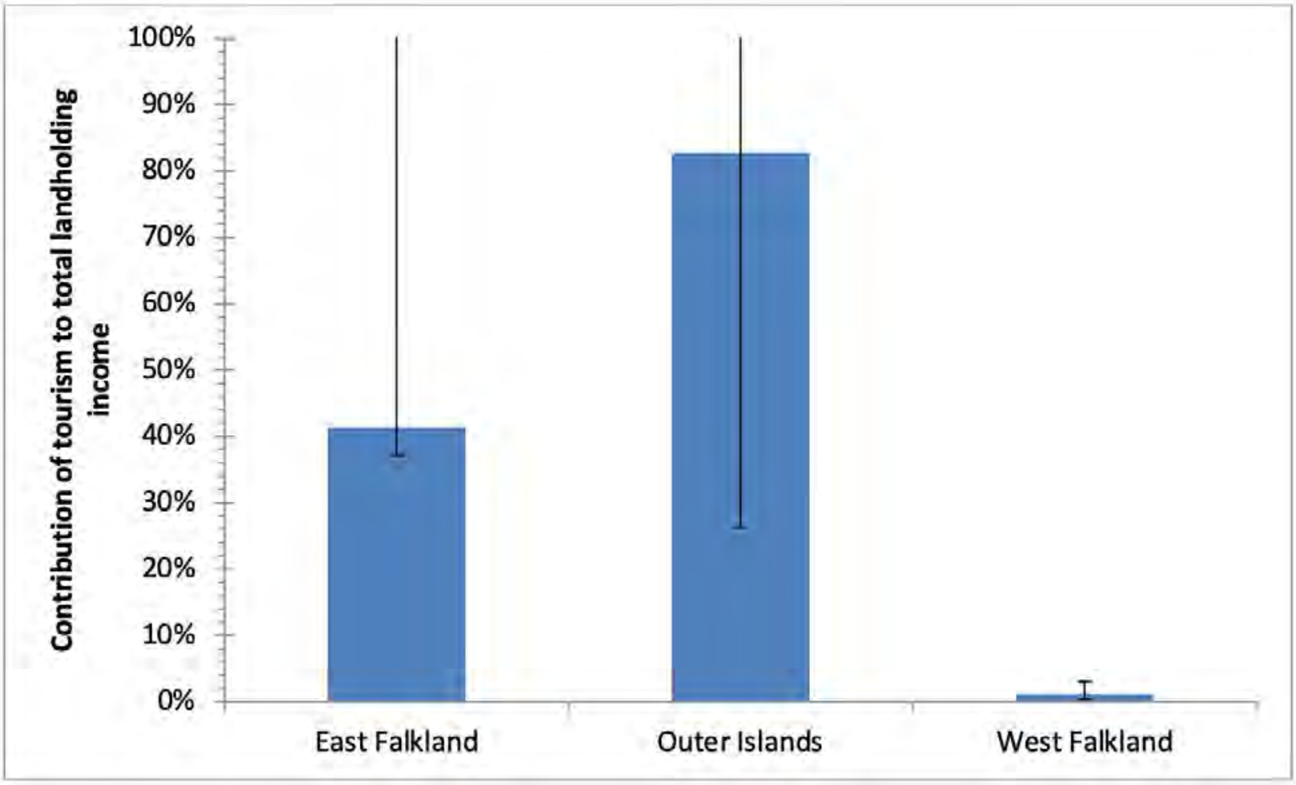

Fig. 4.24: *The average contribution of tourism to total income for those landholdings that had a clear link to marine or coastal-related tourism on East and West Falkland and the Outer Islands for the period 2012-2017. Error bars indicate the range of contribution between different farms for the period. Data courtesy of Falkland Islands Government Policy & Economic Development Unit.*

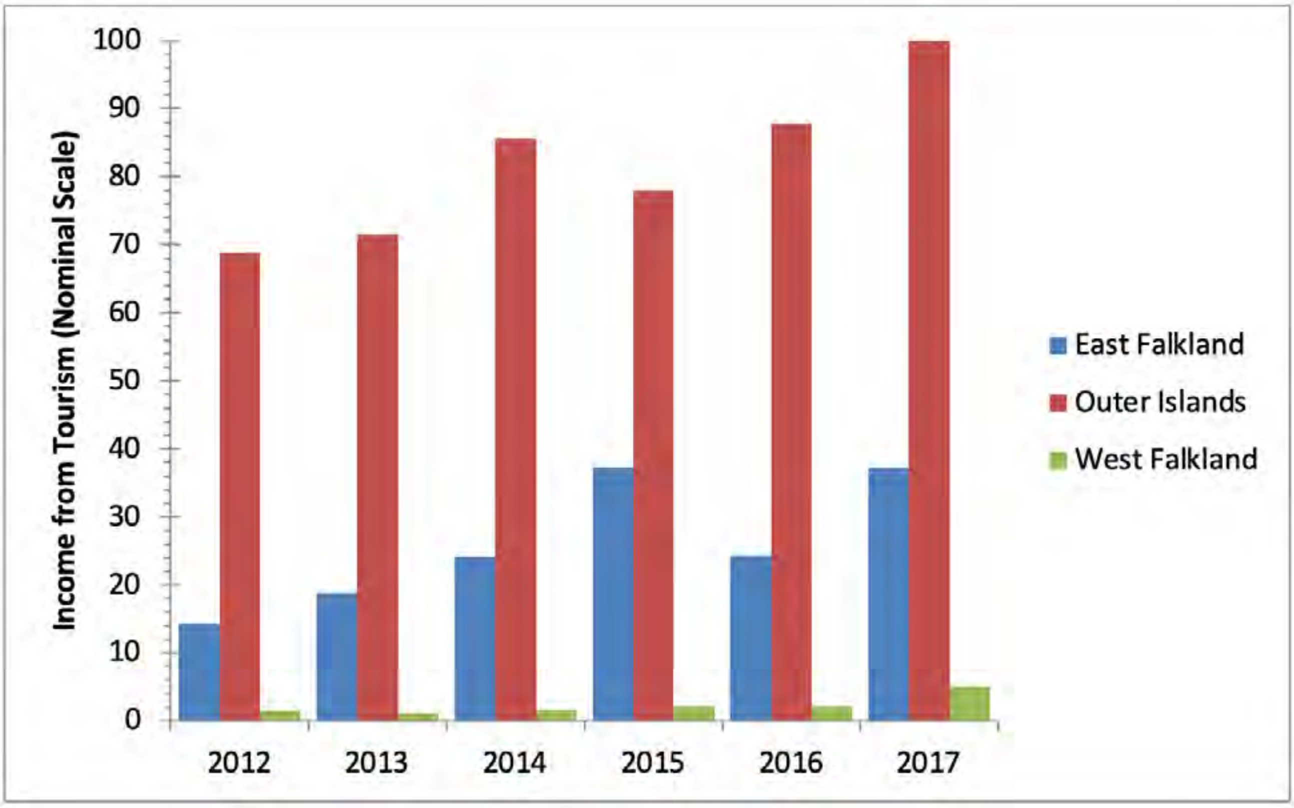

Fig. 4.25: *The average annual income from tourism to individuals for those landholdings that engage in marine-related tourist activities on West Falkland, East Falkland and the Outer Islands. Data have been adjusted to a nominal, relative scale where 100% is the average Outer Falkland Islands value for 2017, the maximum average value from the time series. In other words, all values have been scaled relative to this value to purely show trends, rather than actual income. Data courtesy of Falkland Islands Government Policy & Economic Development Unit.*

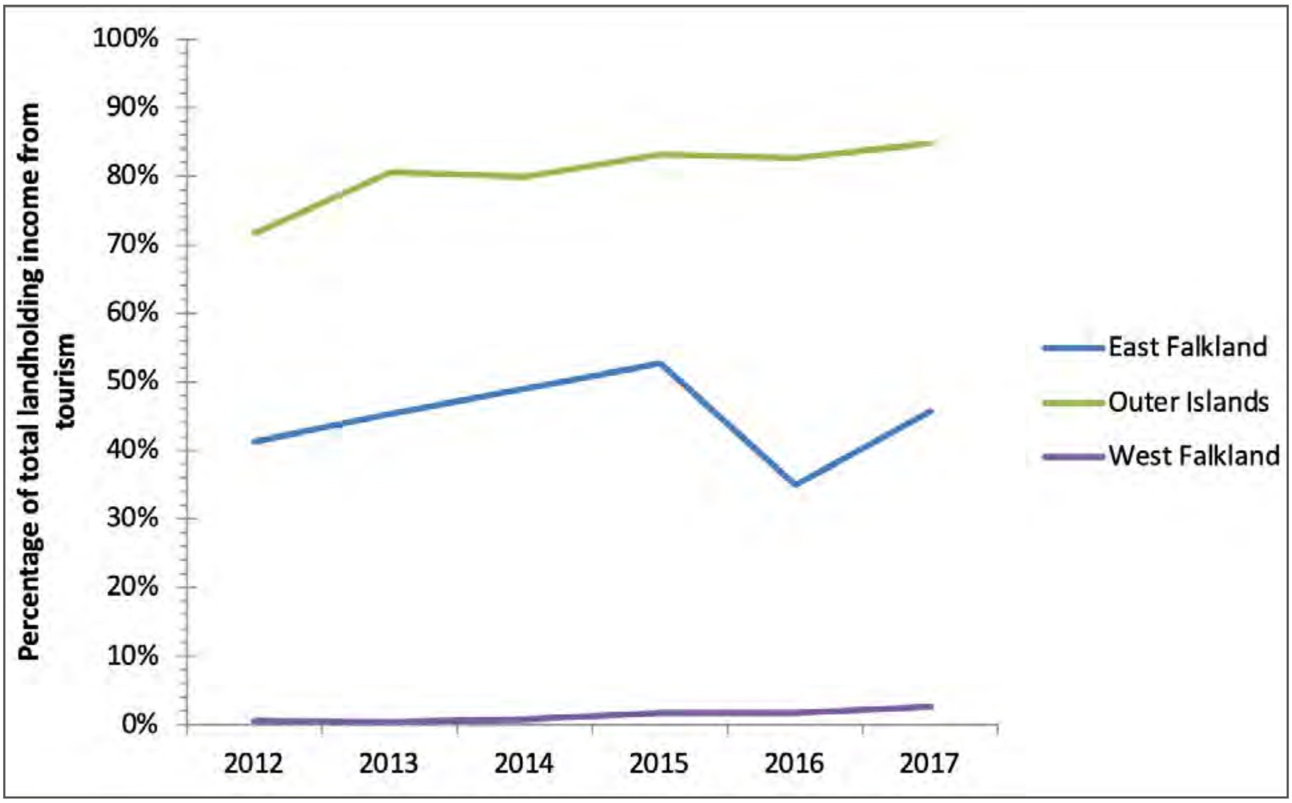

Fig. 4.26: *The average annual contribution of income from tourism to total income for those landholdings who engage in marine-related tourist activities on West Falkland, East Falkland and the Outer Islands. Data courtesy of Falkland Islands Government Policy & Economic Development Unit.*

4. YACHTS AND OTHER LEISURE CRAFT

Fig. 4.27: *The Canache in Stanley harbour area, one of the main sites where local residents store their yachts.*

The Falkland Islands has a small community of yachting enthusiasts. The Falkland Islands Yacht Club (FIYC) has around 15 members at present, and many of them have yachts on the Islands, either at the Canache (Fig. 4.27) or other sites around the Island. There are also visiting yachts to the Islands, which the FIYC collects information on (Table 4.6, 4.7). Visiting yachts mainly dock at the public jetty, though this is typically used for landing cruise ship passengers in the summer limiting availability, or at the Falkland Islands Company Dock, though this is a commercial dock and often used for business activities, in Port Stanley, thus many days are spent at anchor [25].

Based on the number of yacht days spent in the harbour and the average spend per yacht, a total spend of between £96,000 and £178,600 per annum on repairs and restocking of vessels. This does not account for any spends that tourists on board might make on the Islands. The FIYC also believes that the average yacht spend may be slightly inaccurate, possibly an underestimate, as many of the charter yachts that visit the Islands will only complete the FIYC questionnaire (distributed by customs) on their first visit to the Islands and not on subsequent visits, possibly skewing the value towards that of first time and more infrequently visiting yachts. The FIYC believes that there might be possibility for growth of visiting yacht numbers in future, should more berths become available in Port Stanley, as one limiting factor to yachts currently is the shortage of sites at which to dock for longer periods, instead being limited to anchorages. They also state that questionnaires indicate that an increase in secure berthing space could increase the length of yacht stays beyond the current average of 9 days [25].

Table 4.6. Statistics of yachts visiting the Falkland Islands collected through surveys conducted by the Falkland Islands Yacht Club (FIYC). Data courtesy of FIYC.

Season	Number of visiting yachts	Maximum number of yachts in harbour at one time	Visiting yacht days in Stanley harbour	Yacht days spent at anchor	Visiting yachts tied to the pontoons at the Public Jetty	Average spend per yacht	Annual estimated spend (spend * number of yachts)
2016/17	32	-	1442	114	-	£3,000	£96,000
2017/18	47	12	1956	60	312	£3,500	£164,500
2018/19	47	10	1799	147	263	£3,800	£178,600

Table 4.7. Average and maximum size of yachts visiting the Falkland Islands in the 2018/19 season. Data courtesy of FIYC.

	Average	Max
Length (m)	14.5	20
Draft (m)	14.5	3.6
Tonnage	2.3	65

Yachts and MMAs

In and around Stanley, yachts are principally within the Port zone. However, yachts do visit other parts of the Islands, particularly anchoring in the inshore area, at various sites depending on the wind. Thus yacht activity, although very small in scale, does interact with the MMAs. In The Falkland Islands Economic Development Strategy Plan there is a mention that a long term (8-10+ years) action could be to develop a marina and yacht-berthing facility in Stanley harbour [26: page 28], leaving some possibility for an increase in yacht activity in the long-term, though, given the remoteness and challenging weather conditions of the Falkland Islands it seems unlikely that yacht activity around the Islands will become a large-scale activity.

5. HARBOURS, SHIPPING AND FERRY

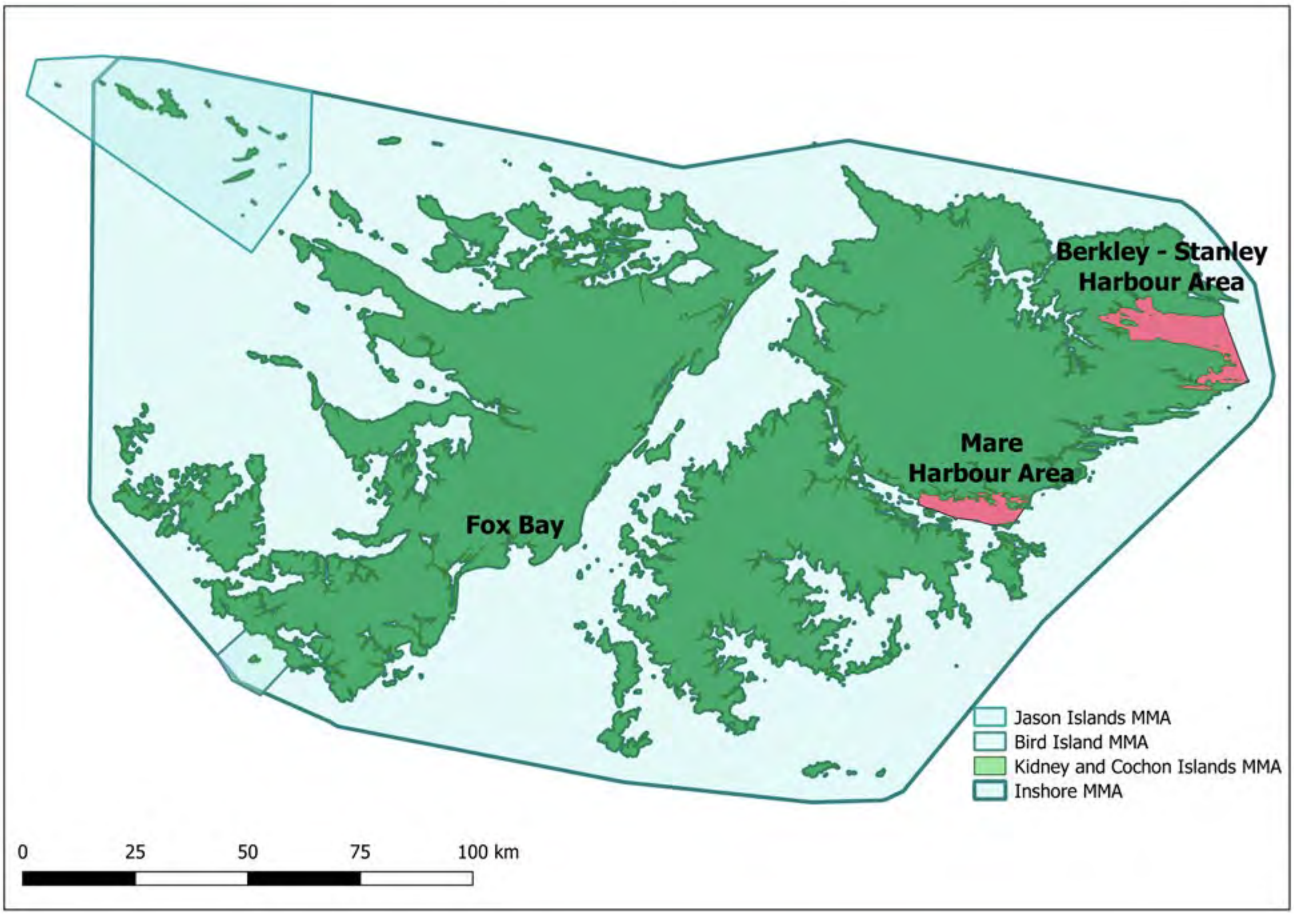

Fig. 4.28: *Map of the Falkland Islands Ports, shown labelled and in pink.*

The Falkland Islands, being fairly remote, depend heavily on their ports and shipping for import of goods like fuel, foodstuffs and specialized equipment, and to export key commodities like fish, wool and meat. Industries such as fisheries, the main source of revenue for the Islands, and the growing tourism industry also depend on them for their direct activities. More remote parts of the Island depend on the local ferry for movement of goods, animals and people[3], and it is the main transport link between West and East Falkland. Ramps, jetties and anchorage sites in Camp are also important for reception of the ferry and other vessels, including some expeditionary cruise vessels at some sites. Ferry and shipping movements to reach these port facilities cross the inshore MMAs, a number of smaller jetties and ramps are located within the MMAs, while all of the designated ports are within the areas zoned as Ports, which are not MMAs but are surrounded by MMAs (Fig. 4.2). These are all considered in this chapter.

The Maritime Authority and the Harbour Master (within the Natural Resources Directorate) oversee the Islands ports, as well as overseeing other aspects like safety at sea, environmental safety at sea, accuracy of hydrographic data on charts and vessel and port inspections (see [27] for further details).

There are four civilian port areas (Fig. 4.28) the principal being Stanley Harbour (also called Port Stanley), which serves the Falkland Islands capital directly and other parts of the Islands through transport links. It is located on the North East of East Falkland and accessed via the entrance to the sea at Port William through the narrows (a small passage). The other ports are: 2) Port William, with a number of anchorages for vessels too large to pass through the narrows or with deep drafts, which provides good shelter from Westerly gales; 3) Berkeley Sound, a deep-water bay located further north, which is a good holding ground for ships and location of ship-to-ship transfer, particularly of squid and fish, and also used for licensed tanker and reefer bunkering operations; and 4) Fox Bay on West Falkland [28], [29]. There is also a UK Ministry of Defence operated harbour, Mare Harbour, south of Port Stanley [29].

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[3] Although, FIGAS does fly to many sites across the Islands, larger cargoes still need to be moved by ship. Additionally, adverse weather conditions alongside challenging landing strips can make some sites difficult to access by air, e.g. New Island. FIGAS flights also can only carry small numbers of people, so some sites depend on larger groups of tourists (e.g. those on expeditionary cruises) arriving by boat. The road network now reaches much of Camp within East and West Falkland, though the two Islands are connected by ferry link only. And the Outer Islands are only accessible by boat and/or air.

Stanley harbour is the most developed of the civilian ports. Within the harbour Falkland Interim Port and Storage System (FIPASS) provides the main berthing area (200 m of berthing space), allowing for transhipment of goods (including fish), offloading of fuel through a specialized fixed fuel line and the loading and unloading of general cargo. FIPASS is made of seven permanently moored barges [29], but the structure was created as an interim port in the 1980's and is in need of replacement in the next few years.

Fig. 4.29: *Falklands Interim Port and Storage System (FIPASS), the main civilian harbour located on the outskirts of the Islands' capital, Stanley, is the main service port and docking facility for fisheries vessels like the one pictured.*

The invitation to tender for a new port development has been put out by FIG on 31 May 2019, with a closing date of 30 August 2019 for tenders [30]. The port is likely to be either in Port William or Port Stanley, with the greatest likelihood that it will be located at or near FIPASS' current location, though this is all still to be confirmed once the tender process is completed and development moves into a later phase. Currently, there is a Demands Requirement Study planned (most likely 2020) to assess the potential for development around the new Port, with the objective of fostering economic growth, and which will involve consultation with multiple stakeholders.

Returning the present layout of Stanley Harbour area, to the East of FIPASS is the Temporary Dock Facility (TDF), which is under lease to Premier oil and is to be used for offshore oil industry support vessels. Still further East is the Canache, which has limited space and is mainly used for small local vessels and yachts. There is also the small, private S.A.M.S. Marina used by local boats. On the North side of Stanley Harbour is the Camber Dock, which has 80 m of berthing face, a 5.4 m depth and is operated by Fortuna Ltd. On the South shore of Stanley Harbour abutting the town (and West of FIPASS), are located the public jetty and pontoons, which are principally used for landing passengers from small craft and launches, although visiting yachts may use these for short periods when the area is not in use for cruise ship tenders. Just to the east of these is East Jetty, which is owned and operated by the Falkland Islands Company Ltd, while to the west is the Maiden Harbour Marina, a privately owned haven for local vessels and visiting yachtsmen that is only accessible at high water [29]. A waterfront master plan, which discusses potential future developments of the berthing facilities and adjacent shoreline, is available on the FIG Environmental Planning Department website [31].

Vessels arriving to or departing from the Falkland Islands are subject to a variety of different customs charges (Table 4.8), and those vessels arriving to a declared harbour are subject to harbour dues, calculated according to the net register tonnage of the vessel and affected by a number of other factors such as period spent in harbour, where the vessel is registered and the number of passengers aboard (see [29]. For example, supply ships (e.g. MV Scout) and British Antarctic Survey research vessels are exempt from paying harbour dues, as are vessels registered in the Falkland Islands and usually employed in trading [29]. Total tax paid by vessels to customs per year ranges between around 1.5 and 2.4 million pounds for the 2008/9 to 2018/19 period, with cruise ships followed by jiggers and reefers being the vessel types that contributed the most (Fig. 4.30). Looking at proportional contribution of different fee types, passenger fees and harbour dues make the biggest contribution to government revenue (Fig. 4.31).

Table 4.8. Summary of relevant harbour and customs duties (valid until 30 June 2019) as recorded in the FIG Port and Harbours information booklet (pp. 33 – 35; The Falkland Islands Maritime Authority, 2019), where more detailed information on harbour dues and other levies etc may be found. Further information on passenger levies and especially how they relate to tourism may be found in Table 4.5.

Fees and taxes	**Cost**
Harbour Dues	***based on net register tonnage***
Designated Ports Entry and Departure Clearance	
Vessels not exceeding 50 net registered tons	£27.20
Vessels exceeding 50 net registered tons	£54.40
Undesignated Ports Entry and Departure Clearance	
Vessels not exceeding 50 net registered tons	£134.90
Vessels exceeding 50 net registered tons	£269.80
Customs Service Charge*	
During normal hours:	£41.30 per hour, minimum charge being for two hours (£82.60).
Outside of normal hours:	£61.95 per hour, minimum charge being for two hours (£123.90).
Passenger Tax (per person)**	£25

*Customs services charges are waived in respect of private pleasure yachts not exceeding 50 net registered tonnes

**where a fee of not less than US$15 is paid for visiting privately owned land in Camp, then passenger fee is reduced to £7.50; see also section on Tourism in this chapter for further details.

***any crew or passengers

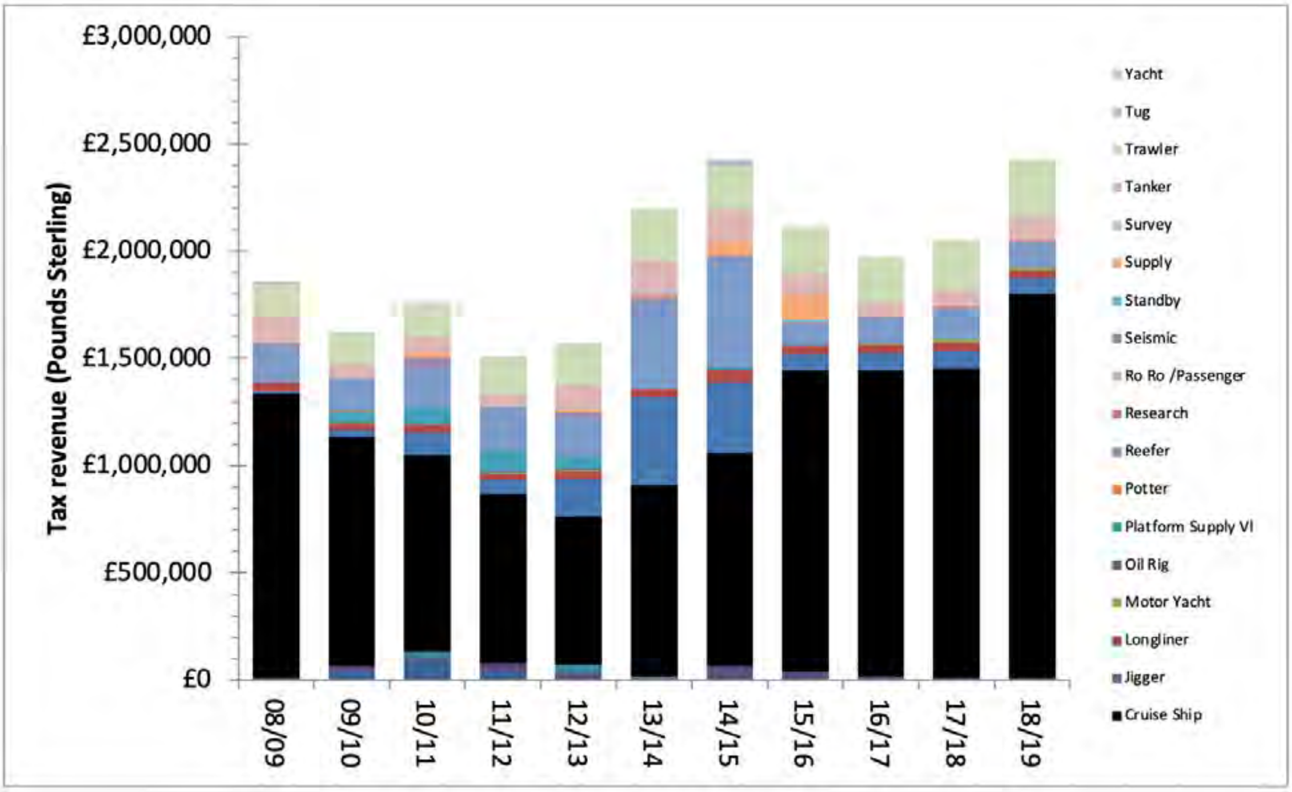

Fig. 4.30: *Total tax revenue from different vessel types visiting the Falkland Islands between 2008/9 and 2018/19. Data courtesy of the Falkland Islands Government Customs and Immigration Service.*

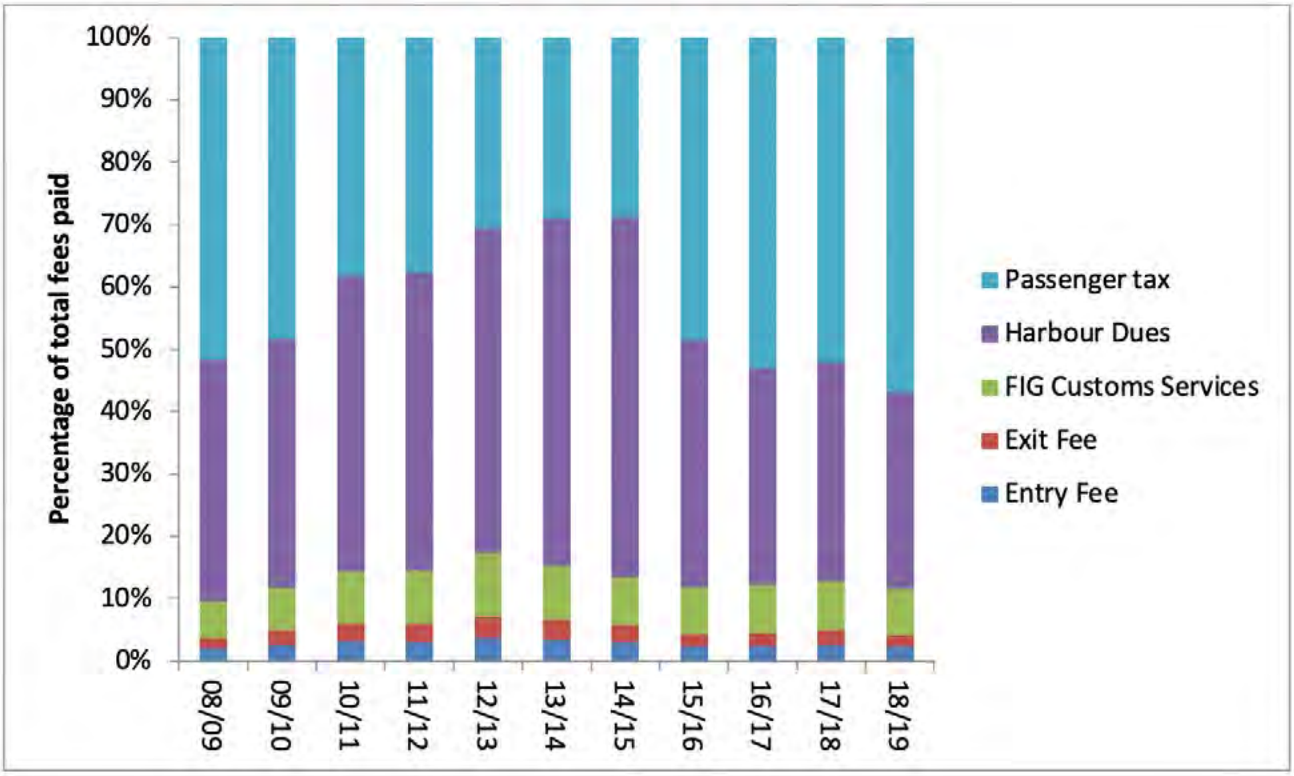

Fig. 4.31: *The proportional contribution (%) by different fee types paid to customs with respect to vessels visiting the Falkland Islands between 2008/9 and 2018/19. Data courtesy of the Falkland Islands Government Customs and Immigration Service.*

Outside of the four designated civilian ports, much of Camp relies on smaller jetties, slip-ways and ramps for the docking of vessels and for ferry access (Fig. 4.32). Some private upgrade of jetties has happened in recent years, such as at Carcass Island, and it is likely that private and publicly funded works will take place in the future. The transport advisory committee has recently approved FIG Public Works Department to submit a report to the Falkland Islands Executive Council for their approval on detailed design and initial works on 13 Island ramps and jetties, which the director of public works estimated would have a project cost of around £2.5 million [32].

The Falkland Islands ferry service falls under the purview of FIG Development and Commercial Services, although it is operated for them by Workboat Services Ltd. The ferry, *Concordia Bay*, is used to link West and East Falkland through the movement of passengers, vehicles and cargo, between New Haven and Port Howard. It also does bulk delivery of fuel to Fox Bay. The jetties at Fox Bay, New Haven and Port Howard are therefore (constantly) maintained [33].

The ferry has also been providing a shipping service and commercial haulage of cargoes like as wool and livestock for the Outer Islands, as well as a private charter contract service since July 2008. This coastal shipping service is a key transport link for the Outer Islands, which they depend on for stores, machinery, mail and fuel, and for three of these islands, which do not have an air service, it is the only and therefore essential transport link [33].

The current contract for the ferry service is still valid for several more years and the service is likely to remain critical into the future. There is ongoing discussion regarding what, if any, upgrades the ferry might require in future to ensure appropriate service delivery over the medium to long-term.

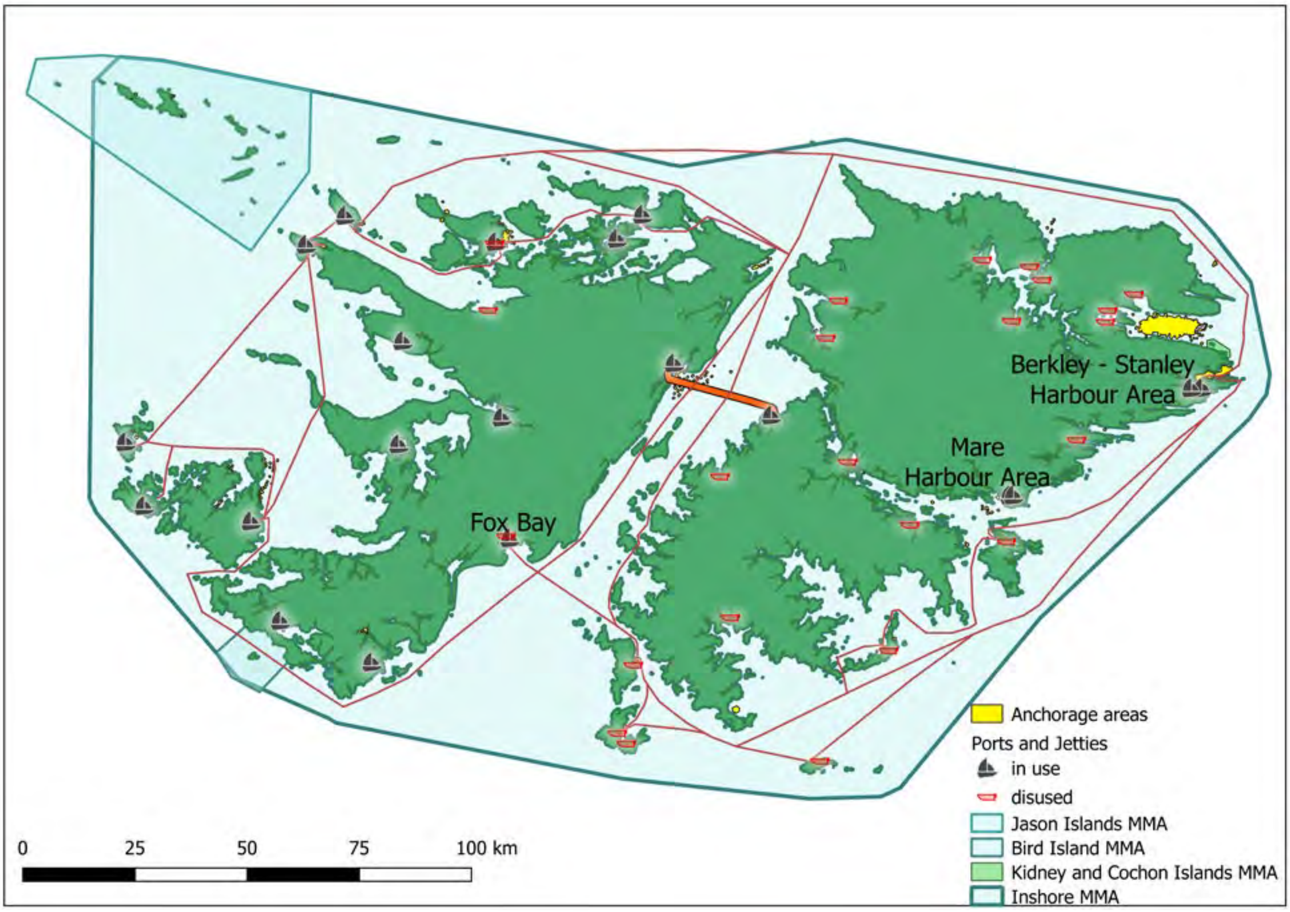

Fig. 4.32: *Map of the main used and disused jetties and ramps across the Islands, as well as principal anchorage areas and the route of the Concordia Bay between West and East Falkland (thick red line), as well as her delivery route to the Outer Islands (thin red line).*

6. AQUACULTURE

Aquaculture refers to the farming of marine and freshwater organisms like fish (e.g. salmon, trout), molluscs (e.g. mussels, scallops), crustaceans (e.g. shrimp, crabs), algae (e.g. seaweeds, kelp) and aquatic plants. The aquaculture sector in the Falkland Islands is currently small, but overlaps with the area proposed as the inshore SMZ MMA (Fig. 4.2).

Specifically, in 2013 a local fishing company invested in a local venture to establish a pilot brown trout farm in the Islands at Fitzroy Sound [35], and have begun marketing Falklands Seatrout to the international market [36]. There has also been interest from the business sector in developing salmon fish farming in the Falkland Islands [34].

7. ENVIRONMENTAL SCIENCE, CONSERVATION AND RESEARCH

The environmental sector of the Falkland Islands could be considered to be made up of research organizations, consultancies and non-governmental organizations working specifically on the natural environment. These organizations include, Falklands Conservation (FC), South Atlantic Environmental Research Institute (SAERI), the New Island Trust (NIT), and to an extent, the British Antarctic Survey (BAS). There are also independent researchers and those linked to organizations here that spend periods on the Islands. This means that much of their area of work overlaps with the MMAs or species and natural environments associated with the proposed MMAs (Fig.4.2).

Information was collected on SAERI, NIT and FC organizations from the UK charity registry [39] and from information kindly provided by the individual organizations, and is compiled in (Table 4.9). Income to these organizations can take a number of forms. Considering these three organizations together, by volume the largest income is probably from acquiring grants (usually linked to projects). Much of these grants come from overseas sources, for example the UK Darwin Plus grants that SAERI receives for many of its projects. Thus, they represent a flow into the local economy.

Income can also come from the Falkland Islands Government awards or local grants like the Shackleton Scholarship (thus circulating money within the economy), from charitable donations and from trading activities to raise funds. For example, SAERI Ltd (the business arm of SAERI) offers consultancy services, FC holds charitable events such as the Conservation Ball where tickets and other items are sold, or NIT offers tourist activities on New Island to cruise ships through the summer (and more recently small levels of self-catering accommodation mainly targeted at domestic tourism). In the case of NIT, it is highly dependent on cruise tourism for its income, and therefore relies on cruise vessels being able to visit the Island. In addition to income, these organizations also hold assets, such as savings and investments, vehicles and, in the case of NIT, an entire Island. Some of these assets require ongoing investment and/or maintenance.

In terms of expenditure and contribution to the economy, in the financial year ending 30 June 2018, total expenditure on charitable activities (by NIT, FC and SAERI combined) was £1.7 million. This is spent on staffing costs (1 part time and 24 full-time employees), goods and services, some of which are local (e.g., hiring of local vessels for research, purchase of food stuffs and other items for resale at charity functions, or for supplies for research and field-campaigns). While one or two staff members per organization are based in the UK, the vast majority are based and therefore paying tax in the Falkland Islands, as well as providing stimulus to the local economy through purchase of goods and services.

Table 4.9. Income and expenditure for three environmental organizations on the Falkland Islands for the financial year ending 30 June 2018, based on publicly available data from the UK Charity Commission [39]. Note that total income from SAERI is likely an overestimate of actual annual income as this figure includes the initial subvention SAERI received when it split from the Falkland Islands Government. Number of staff and projects are based on current numbers at the respective organizations. Data courtesy of Falklands Conservation (FC), South Atlantic Environmental Research Institute (SAERI) and New Island Trust (NIT).

	Income	Expenditure (charitable activities)	Expenditure (governance)	Number of full-time staff	Number of part- time staff	Number of projects
FC	569,432	473,400	14,400	10		39
SAERI	2,031,088	1,190,000	20,000	12*	1*	20
NIT	78,359	67,618		2		7**
TOTAL	**2,678,879**	**1,731,018**	**34,400**	**24 (25)*****	**1**	**66**

*average number of staff (2017-2019)

**Number of projects estimated to have been conducted in association with NIT in 2018/19

*** BAS also employs one full-time staff member based in the Falkland Islands all year.

In addition to providing local employment, the environmental sector contributes to the economy through the attraction of researchers and through the investment of volunteers' time on charitable projects that benefit the Islands. Part of the value in this can be seen as building knowledge capital on the Islands and in skills and knowledge transfer to the residents.

For example, 269 research permits were issued between 2005 and 2017 (Fig. 4.33). While not all of these research permits were for visiting researchers and some were for researchers based on the Islands, a quick estimation can be made by looking at country of origin. Out of 269 researcher permits only 61 were listed as Falkland Islands (23%), while the remaining 77% were listed as countries as diverse as Norway, UK, USA, Australia, South Africa, Portugal and Italy. Research permit length varies from a few days to five years, but consultation with environmental organizations suggest that visiting researchers tend to stay between 10 days and a month, although researchers may often repeat over several seasons. These values should be treated as crude estimates, and to know the full impact of visiting researchers to the Islands a more in-depth study would be needed. Whatever the actual numbers and length of stay, researchers bring skills and expertise that are invested in research on the Islands, generating knowledge capital, and they also spend money on accommodation, food and other goods and services.

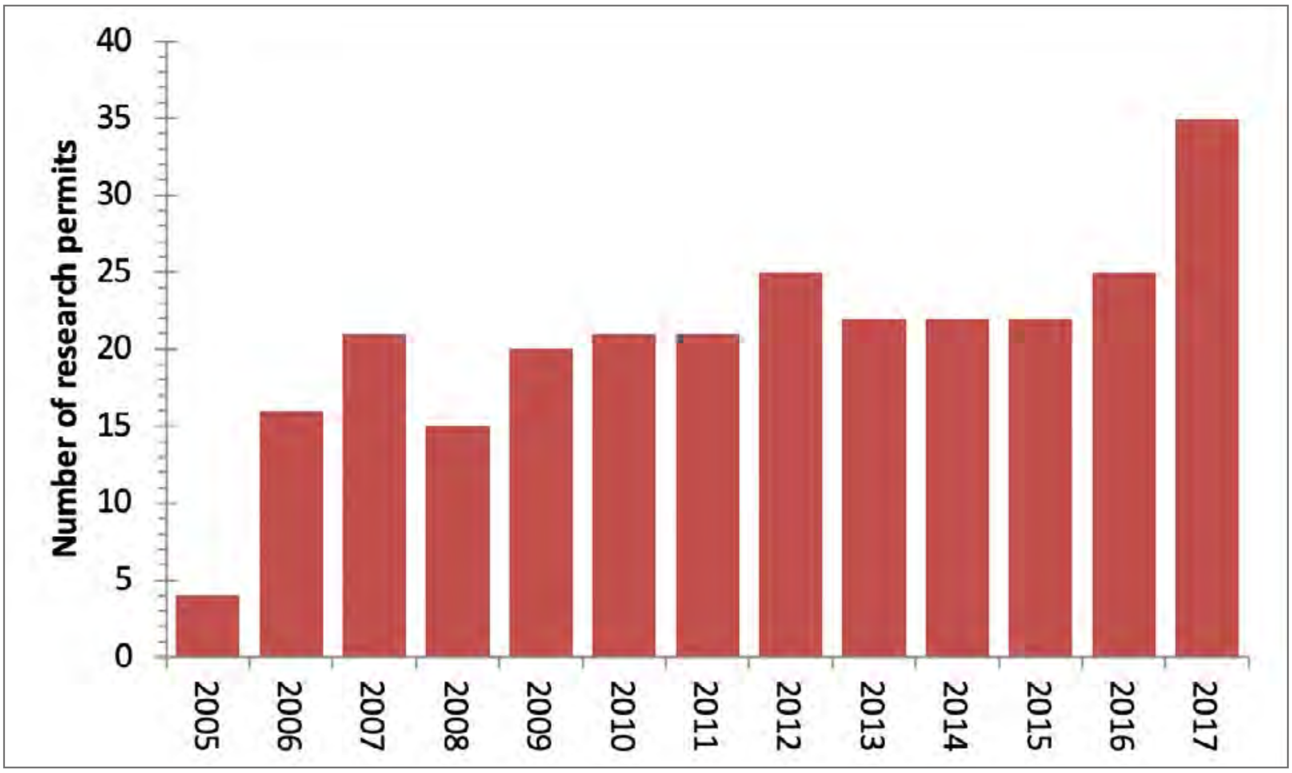

Fig. 4.33: *Number of research permits issued by the Falkland Islands Government between 2005 and 2017. Data courtesy of SAERI and Department of Policy and Economic Development.*

FC secures volunteers to assist with multiple projects on the Islands, such as habitat restoration (like tussock grass replanting), rehabilitation of penguins, outreach and education activities with the student Watch Group, and assistance with organizing and hosting of various charitable events. FC currently has 150 registered volunteers. Examining a time-series of volunteer hours and estimated wage rate for the activities undertaken, based on the ten-month period between 01/08/2018 and 31/05/2019, an annual estimate of 2,397.3 hours valued at £23,105.70 was donated (data courtesy of Falklands Conservation). This value may be higher as it is believed that habitat restoration hours were not fully captured in the data series, and of course does not account for the indirect values, such as value added to restored habitats or educational outreach to children and the community.

Finally, the British Antarctic Survey itself does not conduct research in the Falkland Islands but does rent office space, employ one staff member, resupply and refuel its vessels, purchase supplies for some of its bases, and move significant numbers of researchers through the Falkland Islands, thereby making some contribution to the local economy in the form of purchase of local goods and services and through tax revenue, e.g. embarkation (on outbound flights) or passenger levy. It also has its vessels flagged in the Falkland Islands [40], [41].

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CHAPTER 4.2: AN ASSESSMENT OF THE POTENTIAL ECONOMIC CONSEQUENCES OF PROPOSED MMA DESIGNS ON THE CURRENT AND CURRENTLY PROPOSED ECONOMIC ACTIVITIES IN THE FALKLAND ISLANDS INTERIM AND OUTER CONSERVATION ZONES

This work was commissioned by SAERI in 2019 and elements of the economic landscape of the Falkland Island will have changed. Furthermore, the findings of this chapter are based on assumptions regarding MMAs and categories, described within. This chapter includes views and information provided by key public and private sector stakeholders at the time the report was written.

SUMMARY

In support of SAERI's Fine Scaling the Design of Falkland Islands Marine Management Areas Project, the current study was commissioned. It aims to assess the potential (economic) consequences of the proposed MMA designs on current and currently proposed economic activities which occur in the areas of the Falklands Interim and Outer Conservation Zones (FICZ and FOCZ, or collectively FCZ) that overlap with areas highlighted during the Marine Spatial Planning (MSP) process as potential Marine Management Area (MMA) sites, through the presented analysis and review.

At the end of MSP Phase II different protected area management categories were suggested for the proposed MMA designs following international guidelines. These have subsequently been fine- scaled and put through for comment from the Project Management Group2 (PMG) to arrive at the categories reviewed in this chapter. These proposed categories are guidelines and not national policy themselves and future stakeholder consultation and workshops, as well as the governance process of the Falkland Islands Government itself are still to take place, any of which may result in changes to the present designs. To assist with this ongoing process, SAERI commissioned the present study to provide insights into the economic impacts of the designs as they currently stand, and assuming international equivalencies as discussed.

Therefore, the purpose of this study and report is merely to examine what the hypothetical scenarios of the suggested MMA designs and categories herein, might mean for the different economic activities described in chapter 4.1. Of course these designs and categories are open to interpretation and, depending how (and whether) they are applied will likely result in variations on the consequences described.

The MMA designs and management categories that build on those proposed at the end of the last phase of MSP are discussed in detail in the text. In short, the proposed MMAs (with reference to Fig. 4.2) comprise:

- A Sustainable Multi-use Zone (SMZ) inshore of 3 nm from the baseline, with nested National Marine Nature Reserves (NMNRs) around Kidney, Cochon, the Jasons and Bird Islands,
- A NMNR around Beauchêne Island,
- And in the south of the FCZ, a NMNR on the Burdwood Bank approximately corresponding to the part of the Bank shallower than 200 m, surrounded by the Burdwood Bank Buffer, another Sustainable Multi-use Zone.

Offshore fishing (e.g. longlining, trawling, jigging) is not expected to overlap with any of the MMAs with the exception of the Burdwood Bank Buffer SMZ, which will overlap with the longline sector. The current Burdwood Bank Buffer SMZ design is proposed to be compatible with sustainable fishing. Nevertheless, an assessment of the economic importance of this area to fishing was made. This Burdwood Bank SMZ area appears to have been important for historical catches and catch value of the longline fishery in the area, meaning any limitations on longline fishing in the Burdwood Bank Buffer SMZ would be expected to produce an economic impact to the fishery, based on historical catches.

The National Marine Nature Reserves (NMNRs), including that of the Burdwood Bank (an area generally in waters shallower than 200 m), and the inshore SMZ are not expected to have significant economic impacts on offshore fishing activity (e.g., longlining, trawling, etc). However, the small- scale artisanal mullet and snow crab fisheries as well as recreational fisheries would not be compatible with the Cochon, Kidney, Bird, Jasons and Beauchêne Islands NMNRs. Most of these activities take place around settlements, though, which tend to be away from these NMNRs, so any effect is likely to be negligible. The rest of the inshore area is a Sustainable Multi-use Zone, which is compatible with these small-scale artisanal and recreational fisheries.

For the oil, gas and mineral sector, there is no overlap between current or currently proposed industrial activity (or license blocks) and MMAs. A buffer of 10 km separates the southern-most license blocks from the proposed MMA designs allowing space for vessel line turns. The inshore storage of rig chains on the seafloor would overlap with the inshore SMZ, but as this is not industrial activity it is not necessarily excluded. The oil industry has also raised concerns that the MMAs could cause investor insecurity, though this is difficult to quantify.

For tourism, the inshore SMZ is compatible with tourist and recreational activities. The NMNRs around Cochon, Kidney, Bird, and Jasons Islands would exclude mass tourism, though smaller visitor volumes would be compatible. The NMNR around Beauchêne Island would exclude future development of tourism, but none currently takes place. Similarly, most yachting movements would be unrestricted by the MMAs. Ferry movements and shipping would be compatible with SMZ. NMNR would not be compatible with general shipping. Jetty development and large vessel activity could potentially be limited/restricted in the Jasons, Bird, Beauchene, Cochon and Kidney Islands NMNRs.

All MMAs are anticipated to be compatible with scientific investigation, though the Beauchêne Island NMNR would limit scientific investigation to the essential (subject to permit – as is presently the case). Furthermore, MMAs may offer interesting research opportunities and protected areas could allow access to new sources of international funding.

1.INTRODUCTION, BACKGROUND AND OBJECTIVES

The South Atlantic Environmental Research Institute's (SAERI) Fine Scaling the Design of Falkland Islands Marine Management Areas Project commissioned this study to assist it with an assessment of economic activities in the areas of the Falklands Interim and Outer Conservation Zones that overlap with areas proposed as potential Marine Managed Areas (MMAs). In chapter 4.1 [1], the relevant current and/or currently proposed economic activities (as of March 2019) were identified. This study attempts to assess the potential (economic) consequences of the proposed MMA designs (Fig. 4.2) on these activities.

1.1. Background

1.1.1. The Falkland Islands and Marine Spatial Planning

The Falkland Islands is a United Kingdom Overseas Territory that lies about 300 nautical miles to the east of the South American mainland, and comprises two large islands and around 778 smaller ones (Fig. 4.1). In the waters around the Islands, the Falklands Interim Conservation and Management Zone (FICZ; established in 1986) and the Falklands Outer Conservation Zone (FOCZ), established in 1990 and extending out to 200 nautical miles, give the Falkland Islands control over its fishery [2]. The population of the Islands is small, 3,398 people in 2016, but it has a strong economy, providing for a high standard of living and a wide range of public services supplied by the Falkland Islands Government (FIG) [3].

An assessment of the economic activities that overlap with proposed MMAs is undertaken in chapter 4.1. In short, though, the fishing industry is important to the Islands economy and it accounts for much of the exports, alongside wool and meat [3]. Marine hydrocarbon exploration has already provided a stimulus to the economy, and it is anticipated to have a greater impact should oil production go ahead [3]. Tourism is also a growing industry on the Islands, with 92% of tourists coming by cruise ship, an activity that depends on ports and other infrastructure around the Islands. The Falkland Islands also depend on shipping and ports for imports of industrial and consumer goods, fuel and a good deal of foodstuffs [3]. Internally, West Falkland and the more remote Outer Islands also depend on the ferry (and light craft) as well as small ramps, jetties and anchorage points for the movement of people and goods (especially animals, supplies and anything large), although the Falkland Islands Government Air Service (FIGAS) light aircraft can move a few people or small, low quantity goods to most sites, barring the few Islands that lack airstrips [4]. Small numbers of yachts and other small leisure craft also make use of various jetties, ramps and other anchorage or berthing points around the Islands. Aquaculture also exists on the Islands on a small scale. Finally, the environmental sector (non-governmental, research and consultancy organizations engaged with the natural environment) also does work in the FICZ and FOCZ.

Given the range of different economic activities already taking place and developing in the FOCZ and FICZ and the relatively pristine nature of much of its marine environment, there is bound to be some overlap in activities that necessitates planning. It is presumably against this backdrop that the Islands Plan (2014-2018) committed to sustainable economic and social development, and specifically to *"implement appropriate land and marine spatial planning frameworks to ensure the preservation and management of both the terrestrial and marine environments of the Falkland Islands"* [6: page 26]. To '*enable coordinated and sustainable management of the marine environment'* [7: page 5], the Marine Spatial Planning (MSP) Process was initiated in the Falkland Islands in 2014.

MSP in the Falkland Islands began in July 2014, as a Darwin Plus funded project (MSP Phase I), with the aim of initiating and forming a framework for the MSP process in the Falkland Islands [8]. This was continued in MSP Phase II (2016-2018), in which the South Atlantic Environmental Institute (SAERI), on behalf of FIG, identified potential areas suitable as Marine Managed Areas (MMAs) against international (IUCN) criteria [9]. These MMAs are a form of protected area, that is, areas where the overarching objective is conserving nature, although sites may have other goals as well, so long as they do not undermine this main objective [10]. Protected areas may be defined as: *"A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values"* [10: p.8]. It should be noted that the Falkland Islands MMAs are only one aspect considered under the wider MSP process [11].

Building on this work, the Darwin Plus funded Fine Scaling the Design of Falkland Islands Marine Management Areas project currently being undertaken by SAERI is conducting key baseline work for the effective design and management of these sites [9], and has further refined the designs beyond MSP II. It is in the context of this latest project that SAERI has commissioned the study outlined in this chapter.

1.1.2. The Proposed MMA Designs

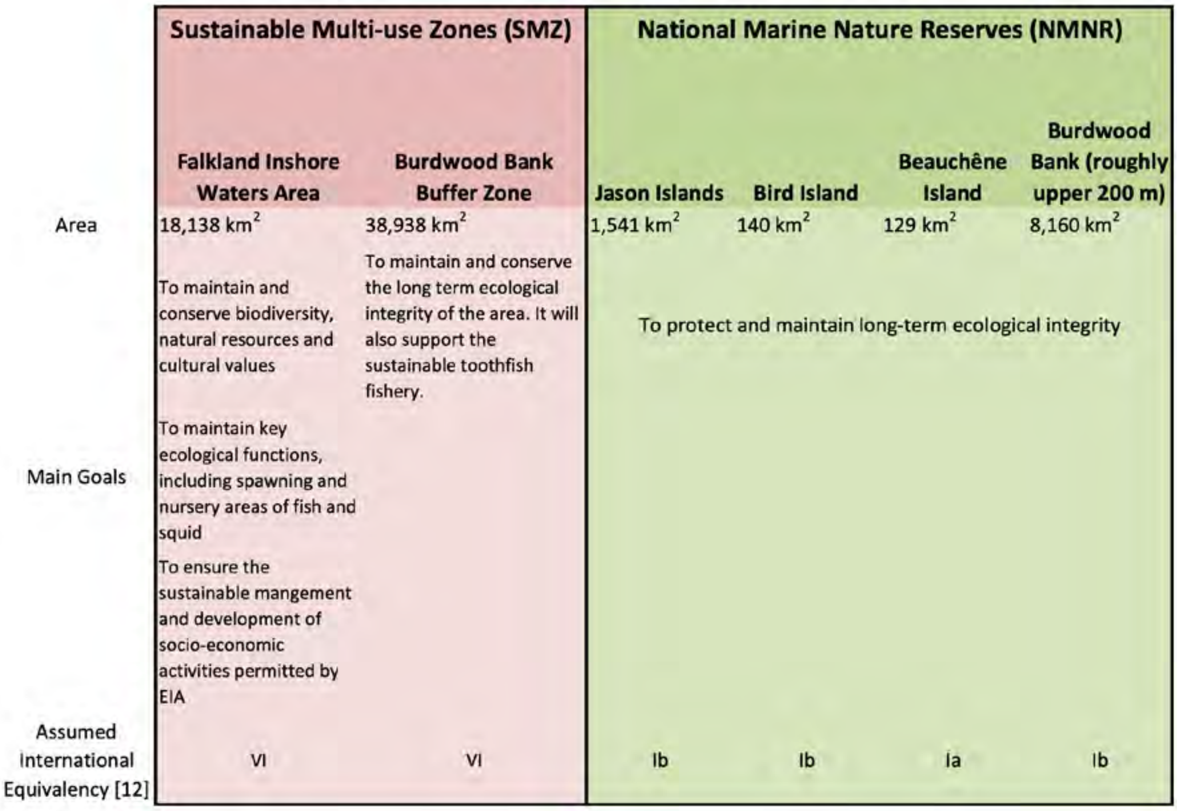
As a result of the MSP Phase II [11] a number of different Marine Managed Area (MMA) designs were proposed, whose locations were largely based on existing Fishing Closure Areas (FCAs) – 3 nm from the baseline and toothfish license seasonal closure area [11]. At the end of MSP Phase II different protected area management categories were suggested for the proposed MMA designs [11], to be used as guidelines for planning purposes[3], using international guidelines for protected area management categories [10]. These designs were then refined by SAERI through a process with the Project Management Group (PMG) of SAERI's Fine Scaling the Design of Falkland Islands Marine Management Areas project to arrive at the MMA framework (Fig. 4.2 and 4.34). It is this framework of MMA designs, assuming some equivalency with IUCN categories as set out in [12] for the purposes of this study, which are assessed in the current study.

It is important to note that the design (fine-scaling) process of MMAs is ongoing at the time of writing this document, which may result in different economic consequences to those described.

Whatever the case may be, categories such as those proposed for the MMAs, or indeed even international categories such as those of the IUCN, are guidelines *and not national policy* themselves. That is, they are a set of guidelines to help facilitate planning of protected areas and protected area systems, and to help with information management and protected area regulation [10]. These guidelines can be useful at helping to direct policy development and MMA design and development, but are applied in different ways by different countries. Presumably the Falkland Islands Government will develop its own specific national policy and legislation for all proposed MMAs.

Indeed, during the designation process of MMAs whether the Falkland Islands Government decides to apply the MMA categories as presently suggested, apply different categories, or create their own categories, is not the purview of the present study and is a separate governance process. *The purpose of this study is merely to examine what the hypothetical scenarios of the suggested categories.* Of course, these categories are open to interpretation and, depending how (and whether) they are applied will likely result in variations on the consequences described in this report. There is still process ahead, including further consultation with government and other stakeholders, as part of the process of fine-scaling the MMAs. It is advisable that throughout MMA policy and management plans development, presumably by government, and once final designation of the sites and the associated policy are ready to be put into place that further consideration, including what the economic consequences of different decisions might be, are taken into account for economic, social and environmental dimensions.

This study merely suggests potential economic implications based on broad categories (which for the purposes of this report were assumed to reflect the IUCN guidelines of [12], similar to the proposal of [11]) and it should not be treated as exhaustive, prescriptive or definitive. Instead, it should be treated as a broad overview of potential economic consequences, bearing in mind that unforeseen consequences can sometimes occur and that specific local policy and legislative developments around MMA will potentially have different effects. Especially given that these broad MMA categories are open to some level of interpretation.



	Sustainable Multi-use Zones (SMZ)		National Marine Nature Reserves (NMNR)			
	Falkland Inshore Waters Area	Burdwood Bank Buffer Zone	Jason Islands	Bird Island	Beauchêne Island	Burdwood Bank (roughly upper 200 m)
Area	18,138 km^2	38,938 km^2	1,541 km^2	140 km^2	129 km^2	8,160 km^2
Main Goals	To maintain and conserve biodiversity, natural resources and cultural values To maintain key ecological functions, including spawning and nursery areas of fish and squid To ensure the sustainable mangement and development of socio-economic activities permitted by EIA	To maintain and conserve the long term ecological integrity of the area. It will also support the sustainable toothfish fishery.	To protect and maintain long-term ecological integrity			
Assumed International Equivalency [12]	VI	VI	Ib	Ib	Ia	Ib

Fig. 4.34: The framework for the MMAs based on earlier work in [11], [12] and work done to date in the Fine Scaling the Design of Falkland Islands Marine Management Areas Project. In its current state, as presented here, the framework was used as the basis for this economic study.

The Sustainable Multi-use Zone (SMZ) MMAs and the National Marine Nature Reserve (NMNR) MMAs proposed will be compatible with different economic activities (Table 4.10). Falkland Islands national legislation and policy, as it is developed, will further dictate the specifics of what could or could not be allowed within a specific area.

The hypothetical scenarios of proposed MMA categorization that are assessed in this chapter are as follows. These categories are based on the proposed designations of the different MMAs (named in Fig. 4.2) resulting from the MSP Phase II process [11], and based on post-AFCAS stakeholder consultation and subsequent development in the Fine Scaling the Design of Falkland Islands Marine Management Areas Project.

- Falklands Inshore MMA – a Sustainable Multi-use Zone based on 3 nm from the baseline but includes Jason West Cay and Eddystone Rock – (assumed to be similar to Category VI in [12])
  - With the exception of:
    - Jasons, Bird, Cochon and Kidney Islands areas to be considered National Marine Nature Reserve (assumed to be similar category Ib in [12])
    - Port areas are designated as ‘Ports’ and not included in Marine Management Areas

- Beauchêne Island – National Marine Nature Reserve based on 3 nm from the baseline (assumed to be similar to category Ia in [12])

- Burdwood Bank Area:
  - Buffer Zone – a Sustainable Multi-use Zone (assumed to be similar to category VI in [12])
  - Burdwood Bank Reserve – National Marine Nature Reserve approximately corresponding to the upper 200 m of the Bank (assumed to be similar category Ib in [12])

Table 4.10. A matrix of marine activities that are suggested as potentially being appropriate for each MMA management category, based on international guidelines [12] and discussions with SAERI on the outcomes of initial discussion with the PMG. Note that fine-scaling of MMA designs is still an ongoing process with future stakeholder workshops anticipated, such that this table and indeed MMA designs may change in future. However, the current chapter and findings therein are based on this table and the MMA designs as presented in this chapter. Comments cannot be made and should not be assumed for any changes to the designs and the contents of this table that may result in future. N.B. This was developed to provide a guide to the economic study. It is likely that a future consultation process will inform on permitted activities in the MMAs.

	National Marine Nature Reserves (NMNR)		**Sustainable Multi-use**
Proposed MMA Category For the purposes of this report assumed to be roughly equivalent to categories in international guidelines [12]	**Beauchêne Island**	**Other NMNRs**	**Inshore & Burdwood Bank Buffer**
	Ia	**Ib**	**VI**
Research: non-extractive	Y*	Y	Y
Non-extractive traditional use	Y*	Y	Y
Restoration/enhancement for conservation (e.g., invasive species control)	Y*	*	Y
Traditional fishing/collection in accordance with cultural tradition and use	N	Y*	Y
Non-extractive recreation (e.g., diving)	N	*	Y
Large scale low intensity tourism	N	N	Y
Shipping (except as may be unavoidable under international maritime law)	N	N	Y

Problem wildlife management (e.g. predator control programmes)	N	N	Y
Research: extractive	N*	N*	Y
Renewable energy generation	N	N	Y
Restoration/enhancement for other reasons (e.g., beach replenishment, fish aggregation, artificial reefs)	N	N	Y
Fishing/collection: recreational	N	N	Y
Fishing/collection: long term and sustainable local fishing practices	N	N	Y
Aquaculture	N	N	Y*
Works (e.g., harbours, ports, dredging)	N	N	Y
Untreated waste discharge	N	N	Y
Mining (seafloor as well as sub-seafloor)	N	N	N*
Habitation	N	N*	N*

KEY

■ No
■ Generally, no, unless special circumstances apply
■ Yes
■ Yes, because no alternative exists, but special approval is essential
■ * Maybe; depends on whether this activity can be managed in such a way that it is compatible with the MMA objectives

1.2. Objectives of the Study

This study aims to provide an assessment of potential (economic) consequences of the proposed MMA designs (Delineations and categories; Fig. 4.2, Table 4.10), as described above, on the current and/or currently proposed economic activities (as of March 2019), identified in chapter 4.1, that take place in the areas of the Falklands Interim and Outer Conservation Zones (FICZ and FOCZ) that overlap with the areas highlighted during the Marine Spatial Planning (MSP) process and which were identified in [11] as potential MMAs. This will be achieved through the presented analysis and review.

1.3. Methods

Data were processed as per chapter 4.1.

Data on the economic activities that overlap with the MMAs of the Falkland Islands were collected through consultation with relevant stakeholders in March to September 2019. Secondary data were kindly provided by a number of stakeholders, including government and non-governmental organizations, or were obtained from online, publicly accessible information and databases (such as TradeMap or Comex). Potential economic consequences are inferred based on the analyses in [1] and the protected area management categories and list of potentially appropriate activities and assuming some equivalency with IUCN categories set out in [12] (Table 4.10) as they are applied to the MMA design scenarios for the Falkland Islands described above in section 1.1.2. [11], [12]. This economic study does not account for specific management plans for the Falkland Islands MMAs as such plans do not yet exist. It is important to note that the specific regulations put in place with the final plans could have different economic consequences to those described here, because, for example, the MMA categories could be interpreted in different ways by local management.

2. ASSESSMENT BY ECONOMIC ACTIVITY

Economic activities that exist or are currently proposed and which overlap with areas proposed as MMAs are identified in chapter 4.1. The potential consequences of the proposed MMA designs from sections 1.1.2. (and shown illustratively in Fig. 4.2) on these economic activities are presented below activity by activity.

It should be noted that there may also be indirect or unexpected economic consequences, which are hard to predict and some of which are likely not to be captured in this chapter. For example, the most recent State of the Falkland Islands Economy Report – in a discussion around changes in annual contributions of different economic activities to total Gross Value Added and how it is difficult to infer the economic consequences of changing industry outputs – states, *"For example, were output from the fishing industry* *to fall significantly, this would be expected to reduce government revenues, and hence ability to spend on public services; it would also affect the businesses that provide support services to the fishing industry. Conversely, a decline in another industry might free-up labour that could be redeployed elsewhere, mitigating the overall negative effects."*[3: p.8]. This illustrates nicely the complexity of interactions within an economy.

2.1. Fisheries

As discussed, fishing is an important economic activity in the Falkland Islands. It accounted for 58.4% of the Falkland Islands GDP in 2016, fluctuating between 35% and 59% over the 2007 to 2016 period [3]. Fishing license fees and the portion fishing companies contribute to corporation tax have been important revenues for FIG (Fig. 4.34). It directly employs a small proportion of Falkland residents (64 staff, or 3.5% of the workforce), but indirectly supports many other industries and the staff that they employ (see [1] for a full discussion).

Fisheries are managed through an individual transferable quota (ITQ) system [13], with the exception of the *Illex* squid (jigging) fishery where licenses are currently sold to foreign vessels on an annual basis. Tax revenues from fishing license fees have been fairly consistent between 2007 to 2018, with the exception of the *Illex* licensing fees which had a higher variability linked to natural variability in *Illex* squid catches between years.

There are some overlap of fisheries catches with MMAs [1], and in terms of licensing areas, the longline license (License 'L') area overlaps with the proposed Burdwood Bank Buffer Sustainable Multi-use Zone and is adjacent to the proposed Burdwood Bank National Marine Nature Reserve (NMNR).

This Sustainable Multi-use Zone is anticipated to allow for sustainable longline fishing, as indicated in Table 4.10, and is therefore not expected to affect existing longline fisheries in the area. If existing fishing activity is allowed to continue in the Burdwood Bank Buffer SMZ, then no economic impact would be expected. The Burdwood Bank NMNR approximately located above the 200 m isobath on the Burdwood Bank is anticipated not to allow for fishing (Table 4.10), but longlining does not currently take place shallower than 600 m because of the general fishing license conditions for longlining set out by the Falkland Islands Government. As such, this NMNR is not anticipated to have any significant impact on existing fishing activities in that area.

However, for good measure to understand any potential economic impacts of different designations or interpretations of international guidelines [12] on fisheries, an analysis was made of historical catch and value time-series by fishing type (Table 4.11) and grid square for the Falkland Islands Conservation Zones. Literature was consulted and interviews were conducted for further insights on existing fisheries. Where geographical overlap occurs, fishing activities were then compared against protected area management categories proposed for the different MMAs, appropriate marine activities per category (Table 4.10), and some international fishing specific recommendations for protected areas (Appendix 1) [12].

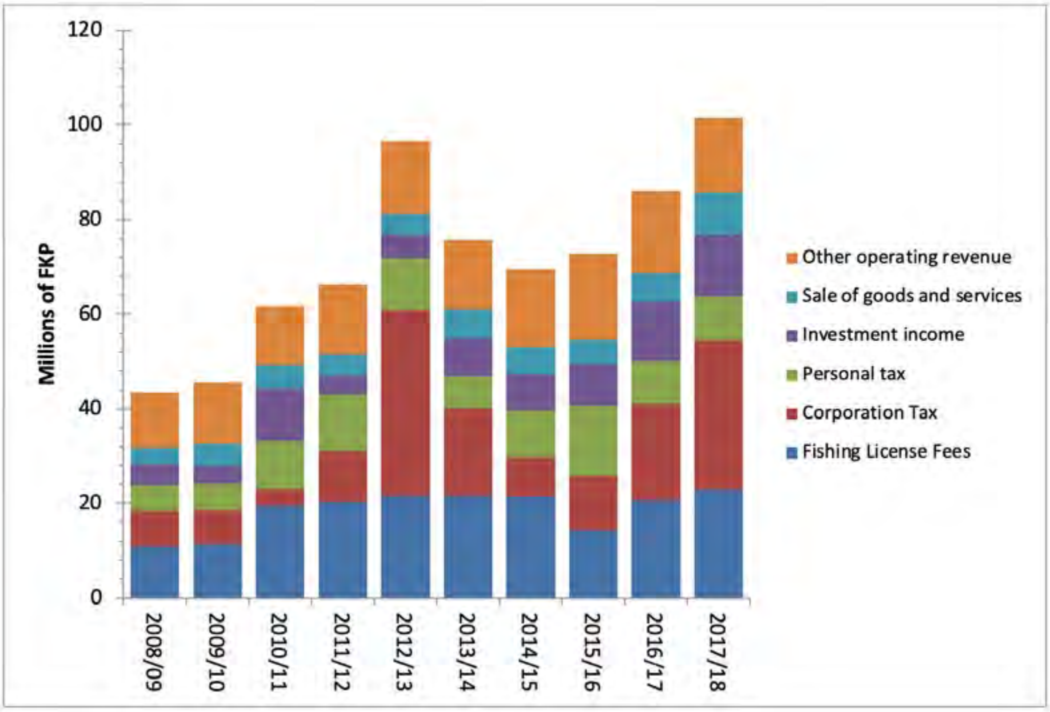


Fig. 4.35: *Revenues earned by Falkland Islands Government 2008/09 to 2017/18, after Fig. 14 in State of the Falkland Islands Economy 2018 Report [3].*

Table 4.11. Fishing type categories used in the fisheries analyses, corresponding categories of Falkland Islands fishing licenses and a short description.

Broad Fishing Category	Corresponding Licenses	Description
Jigging	B	Jigging for *Illex* and *Martialia* squid
Loligo or Falkland Calamari	C & X	Fishing for *Doryteuthis gahi* squid
Finfish	A,G,W, F & S	Trawling for fin-fish, rays and skates
Longlining	L	Longlining for *Dissostichus eleginoides*
Research	E	Experimental fisheries and scientific research

2.1.1. Inshore areas and Beauchêne Island

There is no overlap between offshore commercial fisheries catches and the inshore MMAs (except Jason Islands) or the MMA around Beauchêne Island, as fishing permit conditions stipulate that vessels cannot fish closer than 3 nautical miles from the Falkland Islands baseline [14]; current Fishing Closure Areas (FCAs) are in place at these sites. Thus, the inshore (except Jason Islands) and Beauchêne Island MMAs are not expected to have any direct economic impact on these commercial fishing activities.

There have been smaller scale inshore fisheries active in the area of the proposed inshore MMA in recent decades, however. These include the small-scale beach seine fishery for Falklands mullet (*Eleginops maclovinus*) reported as a minor commercial fishery in 2018 that only produced a modest supply to the domestic market [13], and to primarily have taken place in accessible coastal areas between Stanley and Goose Green, though recreational fishing for mullet (mainly rod and line) takes place on-shore throughout the islands. Recreational catches are likely to be small given the size of the Falkland Islands population. Snow crab (*Paralomis granulosa*) is occasionally caught, with less than one tonne caught in 2018 [13], and is described as an artisanal fishery that has only supplied small quantities to the domestic market.

A Patagonian scallop (*Zygochlamys patagonica)* directed fishery previously existed, but any catch of this species after 2006 has been as bycatch in other fisheries; indeed no scallop-directed fishery took place in 2018 and only 4 tonnes were taken as bycatch in other fisheries [13], [15]. If any scallop fishery were to happen in future it seems unlikely that it would be [licensed] within 3 nm of the coast, as coming inshore of the 3 nm limit was part of the reason for grounding of the scallop fishing vessel in the past.

Apart from the above, there has not previously been any other semi-commercial or commercial fishery in the Falklands' inshore waters. A study of potential inshore fisheries (species) was made in 2016 alongside an economic feasibility study [14;15]. In short, the studies made any development of new inshore fisheries seem unlikely in the foreseeable future and most likely nothing beyond small-scale, artisanal operations.

Considering the categorization of the **inshore MMA** as a Sustainable Multi-use Zone (SMZ) with the nested National Marine Nature Reserves (NMNR) of the Jasons, Bird, Cochon, Kidney Islands and to the South the Beauchêne Island NMNR:

- Offshore fishing activity (longline, trawling, jigging, Loligo, and research) should not be affected as it does not currently take place in those areas proposed as Inshore and Beauchêne MMAs. The exception is the NMNR around the Jason Islands, which extends slightly beyond the current Fishing Closure Areas (FCAs). This area is very small, and overlaps the edges of four grid squares (Fig. 4.36). Collectively, the four grid squares account only 0.378% of the average total annual catch and 0.31% of average total annual catch value for the entire FICZ and FOCZ. As the NMNR around the Jason Islands occupies only a fraction of these four grid squares it likely makes a much smaller contribution to total fisheries catches and value. Thus any economic impact resulting from these areas being closed to fishing – the Jason's NMNR is incompatible with commercial fishing (Table 4.10) - is likely to be very small.
- The mullet and snow crab fishery, provided that they are sustainable, and given that they are non-industrial in scale, should be able to continue in the inshore SMZ areas (Table 4.10).
- As the scallop fishery is not active it should not experience any impact in the inshore SMZ, and if it were to become active, which the fisheries department has indicated as being very unlikely inshore of 3 nm from the baseline (see chapter 4.1), it would presumably also be compatible with these categories if it were to be a non-industrial and sustainable fishery.
- Recreational fishing is also compatible with the SMZ, so this should not experience impacts.
- The NMNRs around Kidney, Cochon, the Jasons and Bird Islands are not compatible with commercial fishing, thus excluding any inshore fisheries (e.g., mullet, snow-crab, scallop) in these areas. Recreational fishing is also incompatible, and only traditional, subsistence or ceremonial fishing activities are compatible with this category. It is difficult to estimate what economic impact

there will be, as it is not clear if much fishing for snow-crab or mullet or recreational fishing takes place in these areas. However, given that the Islands are fairly remote and that the population of the entire Falkland Islands is very small, there is likely to be very little impact. Especially as the terrestrial parts of Cochon, Kidney, Bird and Jason Islands are all reserves and not agricultural/settlement areas as in other parts of the Falklands. Furthermore, discussions with fisheries indicated that low volumes of mullet and snow crab are taken in the entire inshore area and most activity is close to settlements. Thus, the likelihood of any significant economic impact of these NMNRs on fishing activity seems remote.

- The NMNR proposed for Beauchêne Island will exclude all fishing activity (Table 4.10), including even research in most instances. As no fisheries currently take place in the proposed area it should not have a direct economic impact on fishing activity. (Discussions on anchorage see 2.5)

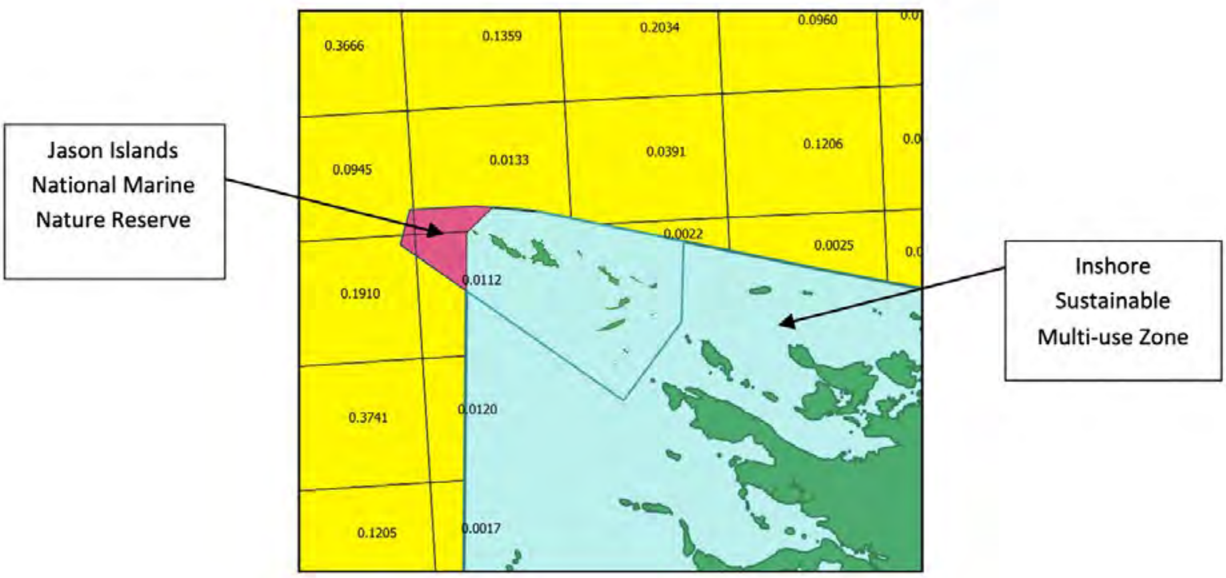


Fig. 4.36: *The inshore MMA (pale blue) and part of the Jason Islands MMA corresponds to current fishing closed areas (FCAs). The portion where the Jason Islands MMA extends beyond the current FCA is shaded purple. Yellow grid square values indicate the percentage contribution that individual grid squares make to the average yearly fisheries value for the entire FCZ, for the years 2007 to 2018. This graph is illustrative not definitive.*

2.1.2. Burdwood Bank

The Burdwood Bank Buffer SMZ overlaps with areas that are commercially fished in the longline fishery, while the Burdwood Bank NMNR (approximately shallower than 200 m) does not, because of current longline fishing license general conditions that do not allow longlining at depths shallower than 600 m. As discussed above, and according to Table 4.10, commercial fishing is generally not compatible with NMNRs, however the Burdwood Bank Buffer SMZ should be compatible with commercial fishing if the MMA objectives allow for it, barring some resolutions on environmentally damaging industrial practices [17]. Ultimately, what fishing is allowed or not in the Burdwood Bank Buffer SMZ will depend on the specific policy and legislation that FIG adopts (see section 1.1.2.).

Based on historical time series of catch and licensing, the Burdwood Bank NMNR (approximately above the 200 m isobath) at first sight appears to cause some economic impact on the longline fishery if harvesting was prohibited in this zone. Although the entire area is currently licensed for longline fishing, it is subject to temporary closures and fishing is not permitted at depths shallower than 600 m, meaning that catches do not actually take place in the NMNR. Permanent closure to fishing, though, would eliminate future options to fish and any direct economic gains from catches in this area. Based on historical catches in the area, it would appear that seven grid squares (that partially fall) within the Burdwood Bank NMNR area made contributions of greater than 0.0010% to average annual longline catches between 2007 and 2018. Collectively they make up 0.9171% of all fish caught by the longline fishery in an historical average year (Fig. 4.37). However, in reality many of these squares fall in shallow waters (< 600 m) where fishing does not actually take place and are therefore likely to not actually have any catches in them, but merely be the midday vessel GPS location reporting.

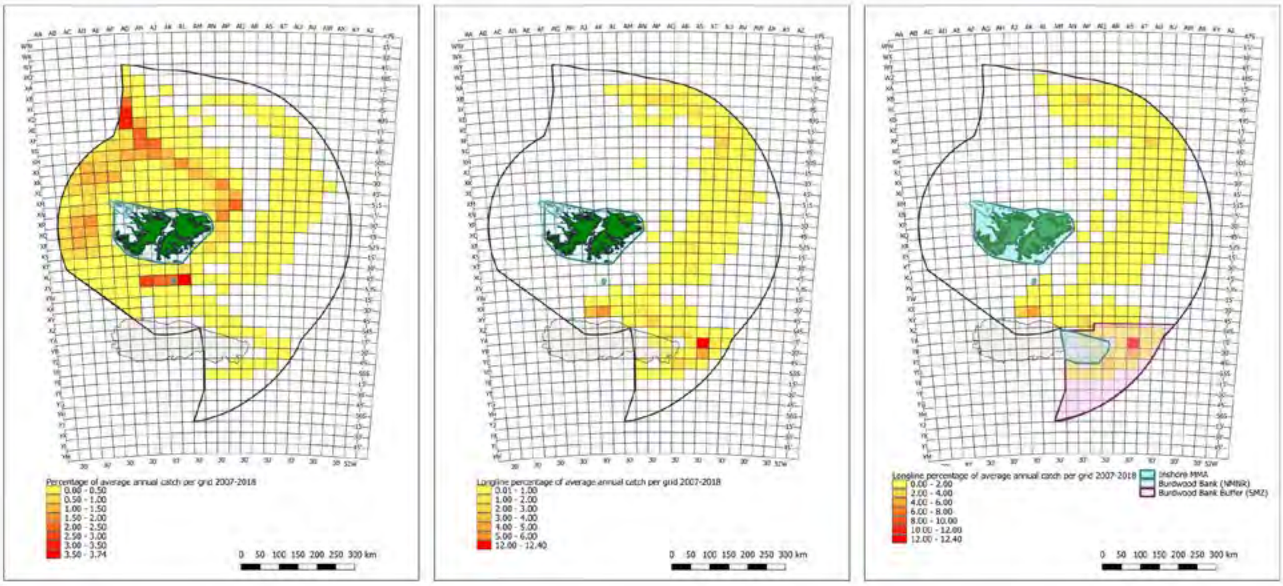


Fig. 4.37: *The proportional (%) contribution each grid square makes to average annual catch volume of the entire FCZ for a) all fisheries combined and b) only longline, as well as c) the overlap between the Burdwood Bank National Marine Nature Reserve (NMNR), the Buffer Sustainable Multi-use Zone (SMZ) and the longline fishery proportional catches. It is evident that the area of the SMZ makes a contribution to total catch value for all fisheries and is especially important for the longline fishery. Data courtesy of FIG Fisheries Department. Note that catches reflected on the bank are probably due to midday vessel GPS locations or due to fishing taking place in other parts of the grid-square (below 600 m); the grid resolution does not show this fine level of detail.*

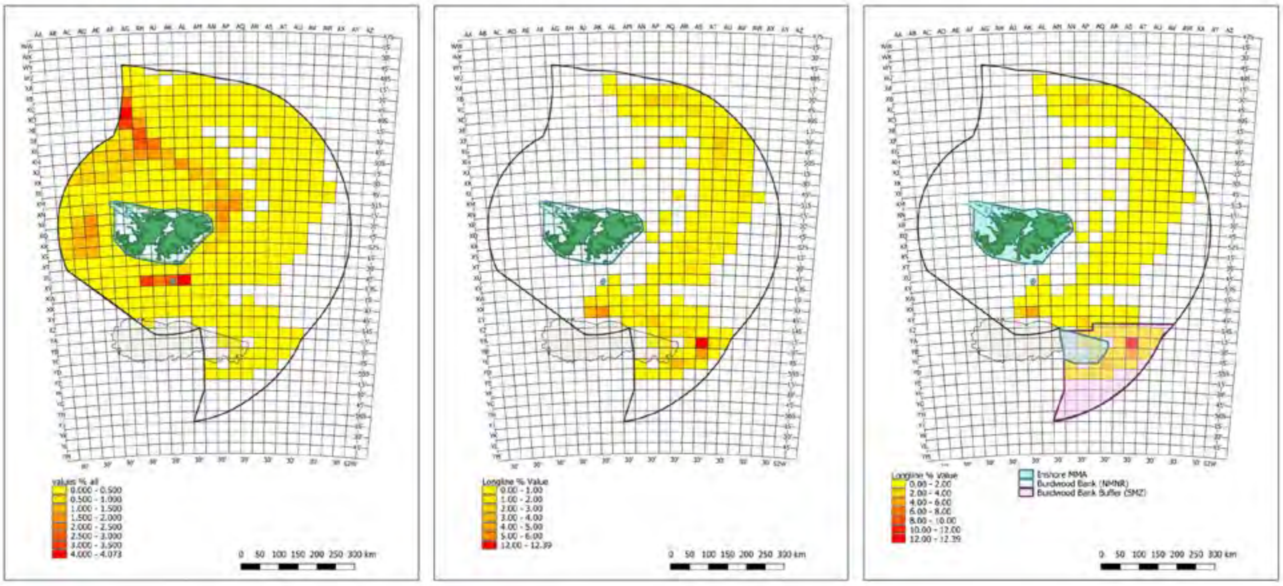


Fig. 4.38: *The proportional (%) contribution each grid square makes to average annual catch value of the entire FCZ for a) all fisheries combined and b) only longline, as well as c) the overlap between the MMAs and the longline fishery proportional catch values. It is evident that the Burdwood Bank Buffer Sustainable Multi-use Zone (SMZ) makes a contribution to total catch value for all fisheries and is especially important for the longline fishery. Data courtesy of FIG Fisheries Department; economic data based on export prices of fisheries product recorded in online, publicly available TradeMap database. Note that catches reflected on the bank are probably due to midday vessel GPS locations or due to fishing taking place in other parts of the grid-square (below 600 m); the grid resolution does not show this fine level of detail.*

In value terms, 0.9718% of the historical average annual value of the longline fishery (2007-2018), appears to be caught within the confines of the proposed Burdwood Bank National Marine Nature Reserve, although as mentioned above, this is taking the upper limit of the entire grid squares, even though many are only partially within the MMA, extending beyond its confines. And again, many of these grid squares are in shallow waters (<600 m), where longline fishing is not currently taking place due to longlining license general conditions, suggesting that any catches either took part at the edge of a grid-square or that the midday GPS position of the boat (to which catches are assigned) did not correspond with the actual catch location. Also, of course, these catch values represent an historical average, so relative impact of the MMA in individual years may vary, or change in future. Nevertheless, the NMNR covers an area that accounts only a small amount of historical catch volume and/or catch value of the longline fishery.

Sustainable (commercial) fishing is anticipated to continue to be allowed in the Burdwood Bank Buffer SMZ; based on this assumption there should be no economic impact in direct catch losses for this SMZ area. This is significant, because the total value of grid squares in the Burdwood Bank SMZ are important to the longline fishery, based on average annual historical catches.

During consultation the fishing industry stated that historical catches may not fully reflect changes in the importance of target species, but rather a mix of fishing permit conditions (e.g. area closures), limitations on catch, and catchability, though presumably these reflect stock abundance in areas to a certain extent. This point probably applies more strongly to the finfish fishery, which has experienced large species composition shifts in catches as opposed to the longline fishery which is more consistent. The industry also stated that historically high catches do not necessarily mean that catches will continue to be high in those same grid squares, given possible changes in the environment, especially with climate change. Thus, marine managed areas, if they exclude fishing, could be viewed as a lost option to the fishing industry. Though, protected areas can also provide an insurance policy against failed stocks (and even extinction) in exploited areas, providing a reservoir of individuals to repopulate areas where extirpation occurs from a complex interaction of variables; the option value motivation behind many protected areas. This paragraph is all speculative discussion, though, and the hard numbers of this are not possible to quantify in the instance of the Falklands Southern MMA.

It is possible that to some extent the losses incurred due to foregone access to harvest areas in the above Burdwood Bank MMA scenarios, could potentially be partially offset by gains in catch volumes in areas adjacent to MMAs [see 18]. Losses could also be somewhat 'mitigated' if fishers can relocate their harvesting activities to other, non-protected sites to sustain catches, but relocation can be assumed to bear a cost, the magnitude of which will depend on positive spill-over effects and on the economics and structure of the industry (monopoly type industries may perceive more sustained economic rents from biological spill-overs) [see 18 for a full discussion]. International studies have found that having well-managed marine areas can allow for the restoration of ecosystems and biodiversity, leading to overall improvements in biomass and body size of individual organisms [19], [20]. There can also be positive spill-over (catch increases) outside the reserve as a result of managed areas, though these do not necessarily compensate for the losses of catch in closed areas, especially over the short term [18], [21]. Such spill-over effects may take a long period of time to be realized and are not certain as many complex factors, such as environment, play a role in this. It has been suggested that marine protected areas may also reduce variance in harvest levels over time (making for more consistent catches), with larger protected areas producing lower variance, which could be more favourable to risk-averse fishers [see 18 for a full discussion].

2.2. Oil, Gas and Minerals

The Falkland Islands is currently in the exploration phase of offshore hydrocarbons, with a variety of exploration licenses issued, none of which overlap with proposed MMAs (Fig. 4.39). This exploration has stimulated the economy and generated revenue to government [3], contributing significantly to the Islands' GVA and should oil production go a greater impact is anticipated [3]. As of 2016, 14 Falkland Islands residents, or 0.8%, were employed in *mining and quarrying, including oil and gas exploration* activities.

As discussed in detail, there is no overlap between currently existing or currently proposed Oil and Gas or mining activities and the proposed offshore, Southern Falklands MMA designs. The closest license blocks lie to the north of the proposed Southern Falklands MMA designs. A buffer of (at least) 10 km separates the proposed MMAs from the hydrocarbon license blocks with the rationale that geophysical survey operations vessels travel at around 4 knots, which should allow approximately an hour for vessels to survey the edge of license blocks and undertake line turns [11]. The Burdwood Bank Buffer SMZ does not exclude shipping movements (e.g. of survey or supply vessels), probably allowing for more flexibility in manoeuvring.

It is difficult to quantify how the proximity of the proposed Falklands Southern MMAs to the licensed blocks will affect the terms of licensing relating to planning for an environmental incident or concerns around this. This will very much depend on specifics adopted in the exact management plans of the MMAs and legislation. Concerns around the proximity to MMAs have been suggested to have the potential to cause some insecurity in terms of future investment in the oil industry, though this is not possible to quantify.

Mining (including oil and gas activities) was previously not compatible with categories I to IV protected areas and in categories V and VI exploration and localized extraction was only accepted in exceptional circumstances where the activities were compatible with the objectives of the protected areas [10]. This has subsequently been updated that for all IUCN categories (including V and VI) industrial activities, such as mining, are not compatible with these areas [22]. On the basis of this international practice and Table 4.10, which incorporates discussion with the PMG, this means that both the Burdwood Bank Buffer SMZ and the Burdwood Bank NMNR would exclude the development of future oil and gas or mining activities in those areas. However, no license blocks are currently anticipated for this area and the Director of Mineral Resources at FIG has indicated that he suspects that the current oil license blocks are about as close to the proposed MMAs that oil license blocks are likely to get, based on the locations of the MMAs and the structure of the seabed (depths, seabed composition etc.), which affect the placement of favourable sites for oil production.

Furthermore, the parts of the FCZ near the south of the Burdwood Bank and to its east are at great depths and in very rough seas, making exploration for oil in these regions highly unlikely, at least in the foreseeable future. In the inshore, there is also no overlap between Oil and Gas industrial activities and sites proposed for the inshore (and NMNR subset) and Beauchêne Islands MMAs. Shipping and logistic related aspects of the Oil and Gas sector will take place in areas zoned as Ports and will therefore be unaffected by the MMAs. Storage of oil rig chains, although a low-probability activity, will need to take place inshore outside of the port areas and this would overlap with the proposed inshore MMA.

Chain storage would not be feasible in the Beauchêne Island NMNR, given its stringent criteria, which even excludes most shipping activity, and also is incompatible with the NMNRs around the Jasons, Bird, Kidney and Cochon Islands. These areas are small, though, and other suitable locations for chain storage could be found, so they should not significantly impact the oil industry economically. Depending on the interpretation of whether chain storage is considered an industrial activity or, just an incidental shipping and storage type activity, it may or may not be compatible with the inshore SMZ (Table 4.10). It would depend on the specific management plans and legislation put in place by the Falkland Islands Government and whether the objectives and conditions of these were compatible with the activity. Based purely on speculation, the most likely scenario, given that chain storage is a low probability and presumably low frequency activity is that it would be considered to have a relatively minor, localized impact and that specific sites where impact to the benthic ecosystems would be lowest would be identified for storage. If this were to happen, the only foreseeable direct economic consequence would be in transport costs to and from these specified locations, and possibly the necessity to conduct environmental impact assessment studies to identify suitable locations.

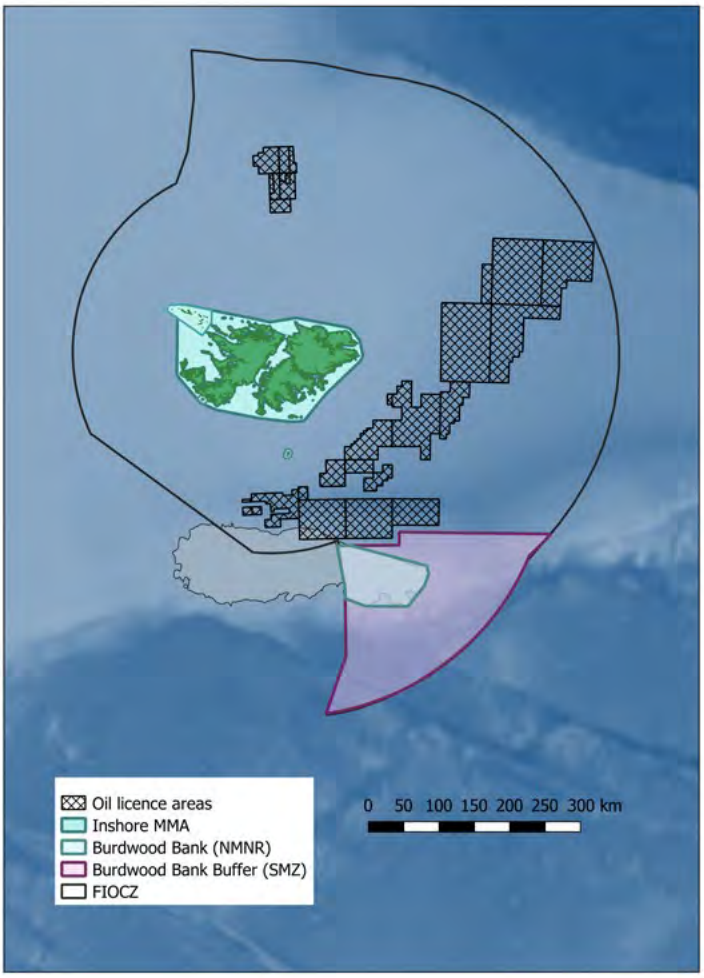


Fig. 4.39: *Map of the Falkland Islands Interim and Outer Conservation Zones indicating oil license blocks and the proposed Marine Management Areas (MMAs). Full details of oil license blocks may be found on the latest Falkland Islands: Offshore Exploration Areas Map on the Mineral Resources Website (http://www.fig.gov.fk/minerals/component/jdownloads/send/21-misc/134-emailable-a4-map).*

2.3. Tourism

Tourism accounted for 1.3% of Falkland Islands GDP in 2016 [3], with a gross value added of FKP£3.8 million in 2016 [23] and £2.9 million, 1.7% of GDP, in 2014 [24], and is a growing activity in the Islands. In terms of employment, 89 people, or 4.9%, cited tourism as their primary employment in the 2016 census, and a further 96 recorded secondary employment in the sector [3]. Tourists come by air (5,565 people in 2018/19 season) through flights landing from the United Kingdom, Chile, and, from November 2019, from Brazil, or by ship (62,505 cruise day visitors in 2018/19 season). On average land-based, leisure tourists stayed 10.4 nights in the Islands and spent FKP£214.09 per night, equivalent to a total of £4.2 million spent over the period, while day visitors spent an average of FKP£64.89 per day, equivalent to a total spend of £4.1 million over the season [25]. In addition to supporting jobs and businesses, cruise ship day-visitors bring in government revenue in the form of a passenger levy, as well as other vessel-related duties. A levy is charged per passenger aboard the vessel; a different fee applies if passengers visit Stanley only or Camp and Stanley together. Total passenger levies collected have increased since 2012/13 to FKP£1,365,872 in 2018/19.

Tourism does not currently occur in the Burdwood Bank Buffer SMZ or Burdwood Bank NMNR, although some cruise ships may pass through this area on their way to the Antarctic or other destinations in the region. The SMZ categorization (Table 4.10), following international guidelines, should not preclude shipping and should therefore not have a direct economic impact. Some shipping (except as may be unavoidable under international maritime law) may be incompatible with the Burdwood Bank NMNR, based on international guidelines [12].

The inshore SMZ is compatible with a variety of economic activities, such as tourism and recreation (Table 4.10), so it should not exclude this activity. Shipping (and therefore movement of cruise ships) through this area is also allowed, meaning that this should not cause any disruption to the arrival of cruise ships to the Islands. One potential impact, which will depend on the specific management plans and legislation finally adopted for the MMAs, could be that more environmental and disaster risk mitigations may need to be put in place for visiting cruise ships, which could bear some financial costs to the cruise ship operators or government. The harbour master identified that with the arrival of more and increasingly large cruise ships there should be consideration regarding risks to the environment and safety at sea (and associated financial) in cases of accidents. For example, the large cruise vessels carry very large volumes of fuel that can pose environmental risks in case of accident.

The Beauchêne Island NMNR will restrict human access to only the most necessary scientific research, excluding tourism. The terrestrial reserve on Beauchêne already has this condition for land visitation. Thus, there are currently no dedicated tourist facilities in this area and the direct impact of excluding tourism in the marine area is therefore likely to be negligible.

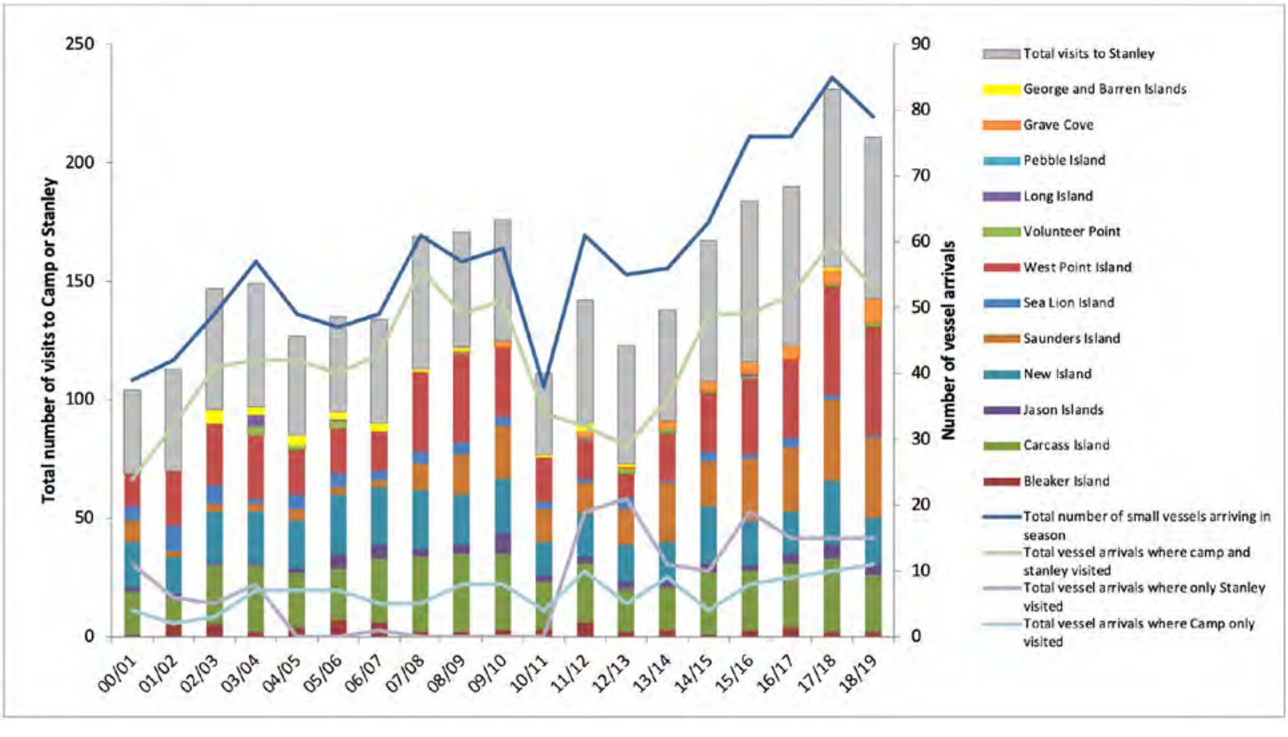


Fig. 4.40: *Number of visits of small cruise vessels (< 600 passengers) to different sites across the Falkland Islands between 2000/01 and 2018/19 (bar graph). There have also been increasing numbers of small vessel (< 600 passengers) visits to the Islands and particularly with itineraries that visit both Camp and Stanley (line graphs). Data courtesy of FIG Customs and Immigration Department.*

The other proposed as NMNRs (Jasons, Bird, Kidney and Cochon Islands) will be more restrictive than the SMZ in terms of the levels of tourism. International guidelines for sites with similar protection levels state that '*Category Ib protected areas will generally be larger and less strictly protected from human visitation than category Ia: although not usually subject to mass tourism they may be open to limited numbers of people prepared for self-reliant travel such as on foot or by boat, which is not always the case in Ia*' [10]. In short, if these NMNRs follow these guidelines, they are likely to be compatible with low levels of tourism. These are generally the kind of tourism already dedicated to these sites, as most visitors are there for the wilderness experience. For example, looking at Fig. 4.40, most of the sites visited fall within the proposed inshore SMZ or ports area, but the Jasons, which falls within area proposed NMNR has only small numbers of vessels visiting it per year. Thus, the inshore NMNRs are not likely to have any negative economic impact to tourism in the foreseeable future, other than prohibiting the development for mass tourism at these sites, which would likely degrade the reason that the sites are visited.

On the upside, protected areas, such as the MMAs proposed, have many positive economic benefits for the development of tourism and recreation; these activities are generally seen to be quite compatible with MMAs. Protected areas can generate economic benefits from the community to national level, provide jobs and income for residents as well as encourage the development of new skills, produce tax revenue, diversify the economy, improve infrastructure with greater sustainability, encourage the development and supply of local goods and services, allow access to new markets and foreign exchange, and generate financing of protected areas through tourism fees and charges [26]. However, organizations such as the IUCN have also cautioned about ignoring potential negative interactions of tourism and MMAs and they point out that careful planning around tourism and MMAs is needed to ensure that development is sustainable within these areas and that negative effects to the MMAs and local communities do not result. Leung et al. provide an excellent discussion of this [see 25].

2.4. Yachts and other leisure craft

The Falkland Islands has a small community of yachting enthusiasts and professionals. The Falkland Islands Yacht Club (FIYC) has around 15 members at present, and many of them have yachts on the Islands, either at the Canache or other sites around the Island. There are also visiting yachts to the Islands, which mainly dock in Stanley port area. Though, some yachts also travel around the Islands visiting and anchoring at various sites. Numbers appear to be low, with between 32 and 47 yachts in the past three seasons.

Yacht berthing within port areas is not affected by MMA designs as these areas are zoned as Ports. The Burdwood Bank MMAs would likely not impact yachts, as this region is not visited by them. The inshore SMZ should not impact yachting activity, either.

2.5. Harbours, Shipping and Ferry

The Falkland Islands, being fairly remote, depend heavily on their ports and shipping for import of goods like fuel, foodstuffs and specialized equipment, and to export key commodities like fish, wool and meat. Industries such as fisheries, the main source of revenue for the Islands, and the growing tourism industry also depend on them for their direct activities. More remote parts of the Island depend on the local ferry for movement of goods, animals and people[8], and it is the main transport link between West and East Falkland. Ramps, jetties and anchorage sites in Camp are also important for reception of the ferry and other vessels, including some expeditionary cruise vessels at some sites. Ferry and shipping movements to reach these port facilities cross the inshore MMAs, a number of smaller jetties and ramps are located within the MMAs and all of the designated ports are within the areas zoned as Ports.

The main ports areas of Stanley, Port William, Berkeley Sound and Mare Harbour will be unaffected by the MMAs as they are zoned as port areas. Although, the Cochon and Kidney Island NMNRs, which will not allow for the passing of shipping through them, may also eventually *indirectly* impose some conditions onto vessels that use the Berkeley Sound area, e.g., through waste management protocols etc. But this will depend entirely on the specifics of the management plans and legislation adopted for these areas.

Vessels will also pass through the inshore SMZ to access ports areas; the SMZ allows for shipping (Table 4.10), so this should not have any direct impact on port, ferry or other shipping activities. Following international guidelines, the inshore SMZ allows for works related to harbour development etc., provided that these follow sound environmental protocols, so categorization of the

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[8] Although, FIGAS does fly to many sites across the Islands, larger cargoes still need to be moved by ship. Additionally, adverse weather conditions alongside challenging landing strips can make some sites difficult to access by air, e.g. New Island. FIGAS flights also can only carry small numbers of people, so some sites depend on larger groups of tourists (e.g. those on expeditionary cruises) arriving by boat. The road network now reaches much of Camp within East and West Falkland, though the two Islands are connected by ferry link only. And the Outer Islands are only accessible by boat and/or air.

inshore should have no impact on development of ramps and jetties development in this zone, other than perhaps adding additional environmental impact assessment type protocols and measures, which would bear some cost to carry out. Similarly, the Burdwood Bank Buffer SMZ, will also allow for shipping to pass through it.

Shipping will, however, generally be incompatible with passing through the Beauchêne Island NMNR, though given the location of Beauchêne and the hazards to ships of generally passing close to shore in shallow depths, it is unlikely that this will significantly impact shipping. Currently, fishing vessels sometimes shelter off Beauchêne Island during rough weather.

Categorization as described in Table 4.10 will exclude this. Thus, some economic consequences could be experienced by vessels, due to needing to travel further to find appropriate sites to shelter outside of the Beauchêne Island NMNR. Some shipping (except as may be unavoidable under international maritime law) may also be incompatible with the Burdwood Bank NMNR, depending on the final management plans for this site.

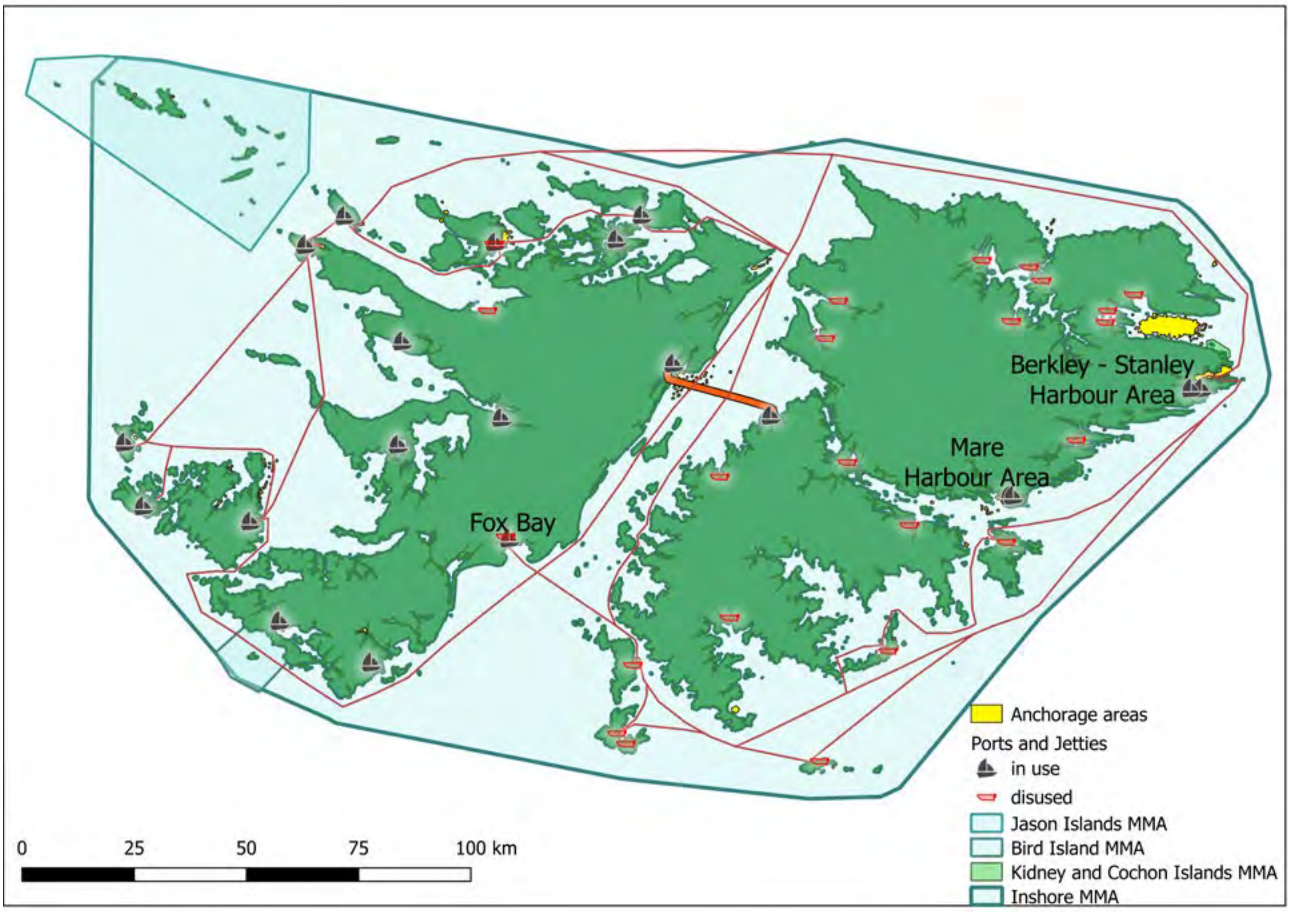

Fig. 4.41: *Map of the main used and disused jetties and ramps across the Islands, as well as principal anchorage areas and the route of the Concordia Bay between West and East Falkland (thick red line), as well as her delivery route to the Outer Islands (thin red line).*

Furthermore, the NMNR categorization of Bird Island and the Jason Islands MMAs (Table 4.10) restricts shipping activity and port and other development within these areas. Looking at Fig. 4.41, there are some anchorage points within the proposed Jason Islands NMNR, but none in the proposed Bird Island NMNR. Both these Islands are unsettled reserves, though, so it seems unlikely that any port, ramp or jetty developments are likely ever to be required, beyond perhaps some very basic constructions on the Jasons to support tourist visits, should the terrestrial reserve so desire, so the economic impact of applying a category similar to Ib to these areas in terms of ports and such development should be insignificant.

On the other hand, the ferry route, an essential service for the Outer Islands, does pass through the Bird Island NMNR, and if its passage were to be excluded as a 'shipping' activity then this would have a serious economic impact for local communities. However, the ferry only makes the journey through this route once every few weeks, so its actual impact is minor to the site and it seems likely that any site management plans would allow for the occasional passage of this essential service through the waters to reach other Islands.

2.6. Aquaculture

The aquaculture sector in the Falkland Islands is currently small, but discussions in local government about developing the sector have re-emerged in recent years [6]. In 2013 a local fishing company invested in a local venture to establish a pilot brown trout farm in the Islands at Fitzroy Sound [5].

In short, future development of the aquaculture sector in the Falkland Islands is uncertain. The inshore location of the current farm (aquaculture facility) in the Falkland Islands, and the location of most marine aquaculture ventures globally, suggests that development of the sector, if it were to proceed, will be in the inshore environment (whether that be fish, shellfish, or kelp).

A 2017 IUCN report provides a useful discussion on aquaculture and protected areas [28]. Based on Table A.2, it can be seen that aquaculture is generally anticipated to be compatible with the SMZ categorization. Thus, the inshore SMZ is not likely to prevent current aquaculture activities from continuing, so long as they align with the MMA objectives and the final MMA policy and legislation put in place by FIG. The final MMA policy and legislation will ultimately determine the scale of current and any future aquaculture and whether it is compatible with the conservation aims of the proposed MMAs.

It is worth highlighting that aquaculture is a broad term. More recent work examining compatibility between aquaculture and protected areas highlights that aquaculture is a hugely varied activity ranging from the small-scale community driven project, to a large-scale, high-intensity industrial activity, and with varied cultivated species ranging from seaweed to marine invertebrates to finfish.

From an economic standpoint, the designation of an MMA may represent costs to current and future aquaculture systems due to costs related in meeting appropriate environmental standards, limitations on size of operations, or other requirements imposed by government. However, these would entirely be dependent on the specifics of the management plan and legislation put in place by FIG.

2.7. Environmental science, conservation and research

The environmental sector of the Falkland Islands could be considered to be made up of research organizations, consultancies and non-governmental organizations working specifically on the natural environment. These organizations attract local and international funding (i.e. attract foreign exchange to the Islands), through grants, charitable donations and commercial activities (e.g. consulting, charity events). This contributes to the local economy through investment in staffing (salaries spent locally and taxes), charitable and other activities on the Islands and through importation of skilled professionals, promoting some skills/knowledge transfer to local communities. They also contribute through volunteer and research projects which add knowledge and other values to the Falkland Islands.

The categorization of SMZs and NMNRs (Table 4.10) all allow for scientific investigation, although the 1a type categorization of the Beauchêne Island NMNR limits this to only essential scientific work that can be done nowhere else, thereby excluding some research. It is not possible to estimate whether this would have any economic consequences for the environmental organizations on the Falkland Islands, but it seems unlikely as research can be conducted at other sites. Conversely the Beauchêne Island NMNR may offer interesting research opportunities. For example, it can be a suitable site to serve as a baseline against which to monitor the relative impact of human activities at comparable sites that allow human access and it can provide ecosystems for study in the most pristine state possible [10].

Research and charitable activity opportunities exist in the absence of MMAs. But regardless of management category applied, protected areas could offer many new opportunities for research, investigation and charitable activities that are compatible with the objectives of the marine managed areas. They could also offer access to new sources of funding specifically related to protected areas, e.g. the Global Conservation Fund.

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APPENDIX 1

Table A1: General guidance from the IUCN on the compatibility of fishing/collecting activities in different management categories, after Table 6 in [12]. At the time of writing, these were the current IUCN guide lines. However, IUCN frequently update and change guidelines related to IUCN categories Ia-VI.

IUCN category	Long term and sustainable local fishing/ collecting practices	Recreational fishing/ collecting	Traditional fishing/ collecting	Collection for research
Ia	No	No	No	No*
Ib	No	No	Yes**	Yes
II	No	No	Yes**	Yes
III	No	No	Yes**	Yes
IV	Variable#	Variable#	Yes	Yes
V	Yes#	Yes	Yes	Yes
VI	Yes#	Yes	Yes	Yes

KEY

* any extractive use of Category Ia MPAs should be prohibited with possible exceptions for scientific research which cannot be done anywhere else.

** in Categories Ib, II and III MPAs traditional fishing/collecting should be limited to an agreed sustainable quota for traditional, ceremonial or subsistence purposes, but not for purposes of commercial sale or trade.

whether fishing or collecting is or is not permitted will depend on the specific objectives of the MPA

Table A2: A matrix of the compatibility of different IUCN protected area management categories and different types of aquaculture, after [28]. The original authors state that this is only an illustrative matrix and is not officially adopted by the IUCN as it would first need to undergo full discussion and dialogue. Please note that IUCN guidelines were updated in December 2019, after this report was commissioned and produced. The compatibility of different aquaculture activities within IUCN categories has changed, and industrial-scale aquaculture is unlikely to be compatible with IUCN categories.

Categories	Ia	Ib	II	III	IV	V	VI
High density fish cage culture	N	N	N	N	*	*	*
High density on-land close system fish culture	N	N	N	N	*	*	Y
Medium density on-land circulating system fish pond culture	N	N	N	N	*	Y	Y
High density shell fish culture (table, long-lines)	N	N	N	N	*	*	Y
Low density pond /lagoon fish culture	N	N	N	N	*	Y	Y
High density seaweed culture	N	N	N	N	*	*	Y
Low density shellfish culture	N	N	N	N	*	Y	Y
Medium density invertebrate (e.g. sea cucumber) culture	N	N	N	N	*	Y	Y
Integrated Multi-trophic culture	N	N	N	N	*	Y	Y
Restoration purpose aquaculture *	*	*	*	*	*	Y	Y

KEY

N No

N* Generally no, unless special circumstances apply

Y Yes

Y* Yes because no alternative exists, but special approval is essential

* Variable; depends on whether this activity can be managed in such a way that it is compatible with the MPA's objectives