

## CHAPTER 2

# OFFSHORE MARINE MANAGED AREAS



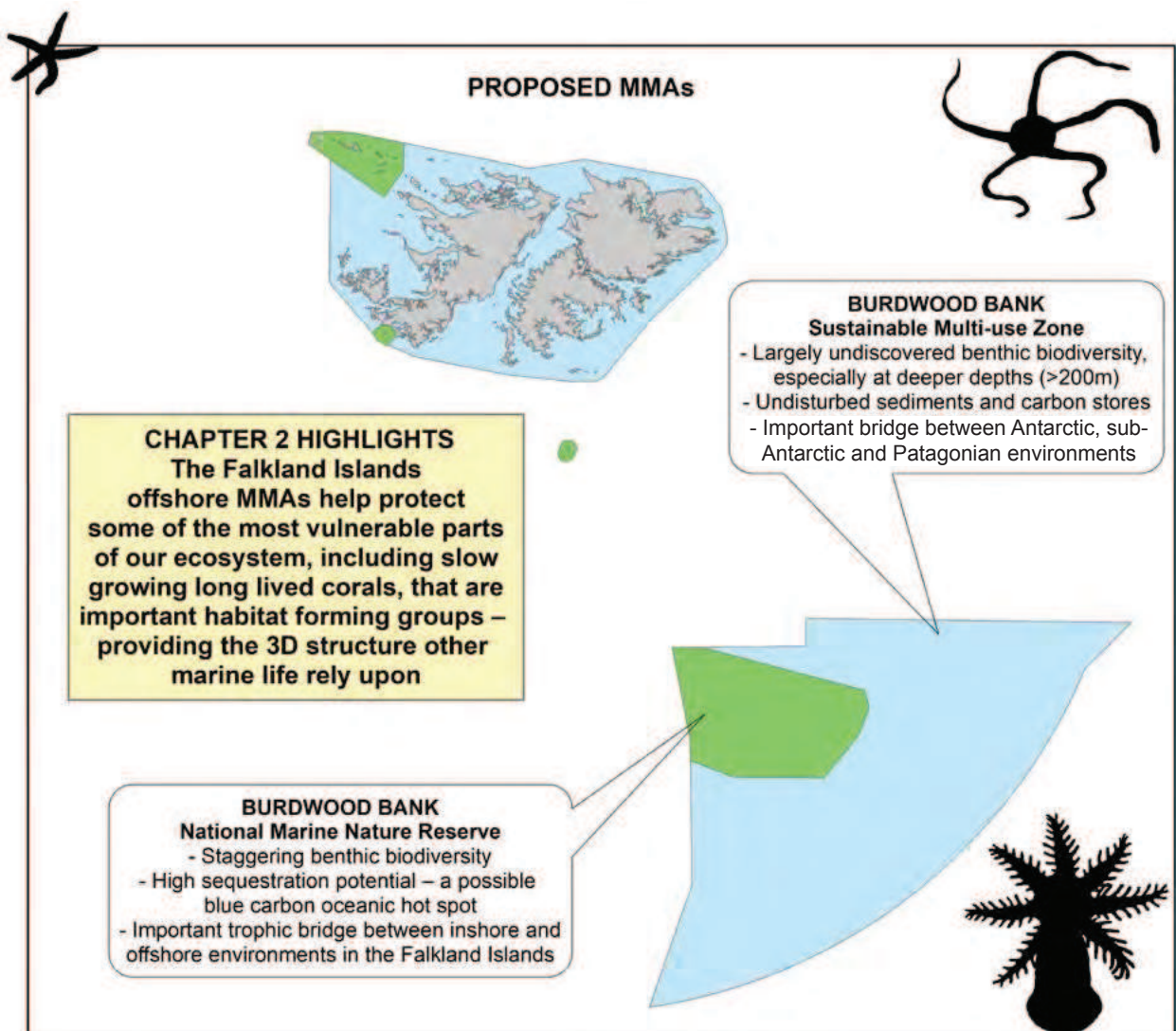
Image: *Gorgonian coral with the arm of an Astrotoma agassizii brittle star* © Noe Sardet.

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# 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.





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<sub>2</sub> 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 36 924 km<sup>2</sup>, 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<sup>2</sup>).
- 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 Gorgonacea 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:

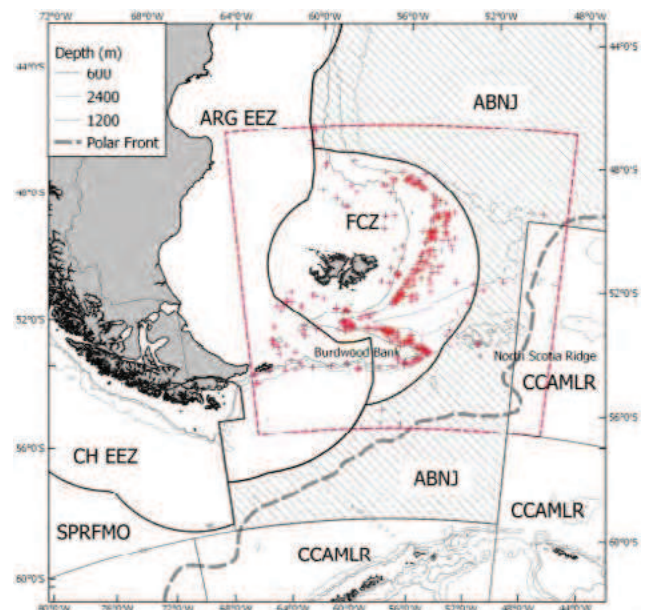
Fisheries pressures and demands are increasing globally and locally (Halpern et al. 2015), consequently, so are the associated impacts of fishing on species and habitats that directly or indirectly support fisheries productivity (Borja et al. 2016). Seabed (bottom-contact) fishing methods can be particularly 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.



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 RFMO/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](http://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) (Kroodsmas 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 are 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 Dudgeon, 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
<b>Seabed terrain</b>					
Bathymetry <sup>a</sup>	M	0.0083	–	<a href="https://www.gebco.net">https://www.gebco.net</a>	GEBCO_2014 (v20150318)
Slope <sup>a</sup>	Degrees	0.0083	–	Derived from Bathymetry	Hogg et al. (2016)
Bathymetric Position Index (BPI) - broad <sup>a</sup>	-	0.0083	–	Derived from Bathymetry	Anderson et al. (2016a)
BPI - fine <sup>a</sup>	-	0.0083	–	Derived from Bathymetry	Anderson et al. (2016a)
TRI <sup>a</sup>	-	0.0083	–	Derived from Bathymetry	Wilson et al. (2007)
Roughness	-	0.0083	–	Derived from Bathymetry	Wilson et al. (2007)
Aspect - northness <sup>a</sup>	-	0.0083	–	Derived from Bathymetry	Hogg et al. (2016)
Aspect - eastness <sup>a</sup>	-	0.0083	–	Derived from Bathymetry	Hogg et al. (2016)
Curvature - general <sup>a</sup>	-	0.0083	–	Derived from Bathymetry	Wilson et al. (2007)
Curvature - planar <sup>a</sup>	-	0.0083	–	Derived from Bathymetry	Wilson et al. (2007)
Curvature - profile <sup>a</sup>	-	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
<b>Seabed sediment</b>					
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 <sup>a</sup>	%	0.05	–	dbSEABED	Jenkins (2019)
Sand: gravel <sup>a</sup>	-	0.05	–	dbSEABED	Jenkins (2019)
Sand: mud <sup>a</sup>	-	0.05	–	dbSEABED	Jenkins (2019)
<b>Productivity</b>					
SS ChL <sub>a</sub> Mean/C.V. <sup>a</sup>	mg m <sup>-3</sup>	0.04	Monthly	MODIS-A L3 SMI 2002-17	<a href="https://oceancolour.gsfc.nasa.gov">https://oceancolour.gsfc.nasa.gov</a>
<b>Physical water properties</b>					
SST mean/C.V	°C	0.04	Monthly	<a href="http://sose.ucsc.edu">http://sose.ucsc.edu</a>	Mazloff et al. (2010)
Seabed Temp mean/C.V <sup>a</sup>	°C	0.04	Monthly	<a href="http://sose.ucsc.edu">http://sose.ucsc.edu</a>	Mazloff et al. (2010)
Seabed salinity mean/C.V <sup>a</sup>	PSU	0.04	Monthly	<a href="http://sose.ucsc.edu">http://sose.ucsc.edu</a>	Mazloff et al. (2010)
Seabed density mean/C.V <sup>a</sup>	kg m <sup>-3</sup>	0.04	Monthly	<a href="http://sose.ucsc.edu">http://sose.ucsc.edu</a>	Mazloff et al. (2010)
Seabed current speed mean/C.V <sup>a</sup>	m s <sup>-1</sup>	0.04	Monthly	<a href="http://sose.ucsc.edu">http://sose.ucsc.edu</a>	Mazloff et al. (2010)
<b>Chemical water properties</b>					
Aragonite saturation state <sup>b</sup>	μmol kg <sup>-1</sup>	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Dissolved oxygen	μmol kg <sup>-1</sup>	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Dissolved inorganic carbon	μmol kg <sup>-1</sup>	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Calcite saturation state	μmol kg <sup>-1</sup>	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Nitrate	μmol kg <sup>-1</sup>	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Silicate	μmol kg <sup>-1</sup>	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Phosphate	μmol kg <sup>-1</sup>	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)
Total Alkalinity <sup>a</sup>	μmol kg <sup>-1</sup>	1.0	–	GLODAPv2.2016b	Lauvset et al. (2016)

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

<sup>a</sup>Factors retained after the examination of correlation matrices

<sup>b</sup>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 (N¼2496). 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 (Kroodsmá 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 (Kroodsmá et al. 2018). The product used in the present study was gridded (1 km<sup>2</sup> 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

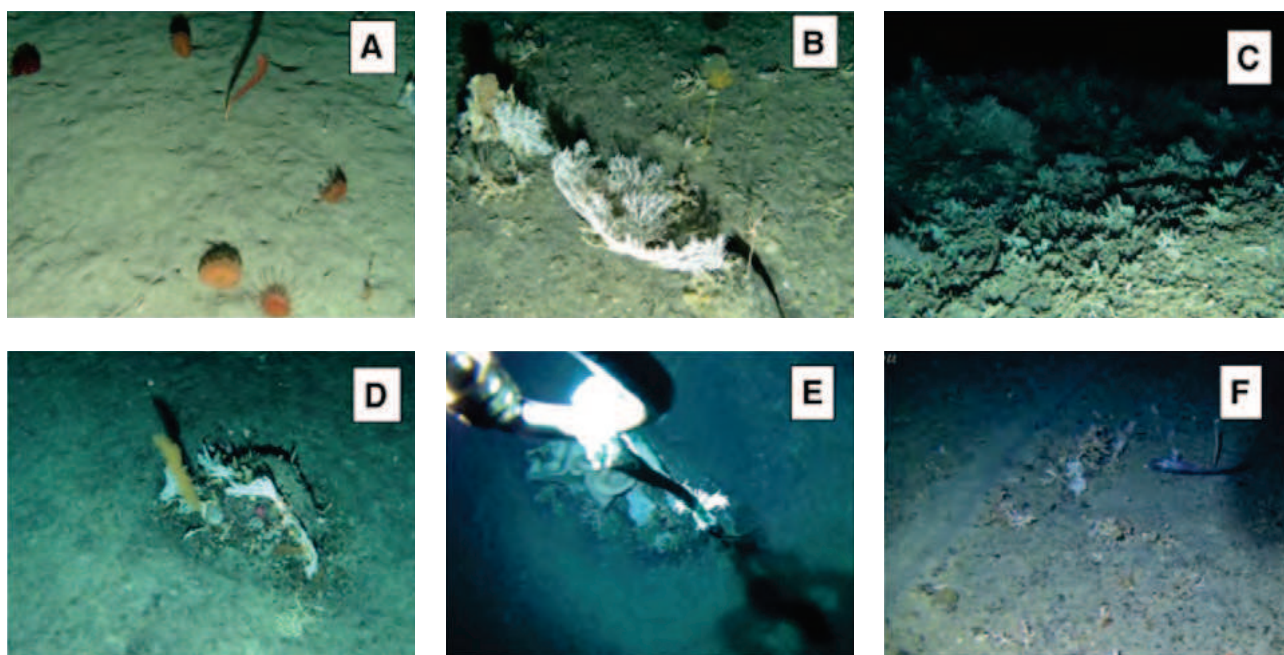
ABNJ fisheries at the native spatial scale of GFW data (1km<sup>2</sup> scale resolution), and fishing effort represented as the effort (total h km<sup>2</sup>) across years per grid square”. All analyses were performed in R (v3.5.1) and QGIS (v3.4.2) and spatial data were projected in the coordinate system UTM21S for the calculation of areas (km<sup>2</sup>).

## 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.

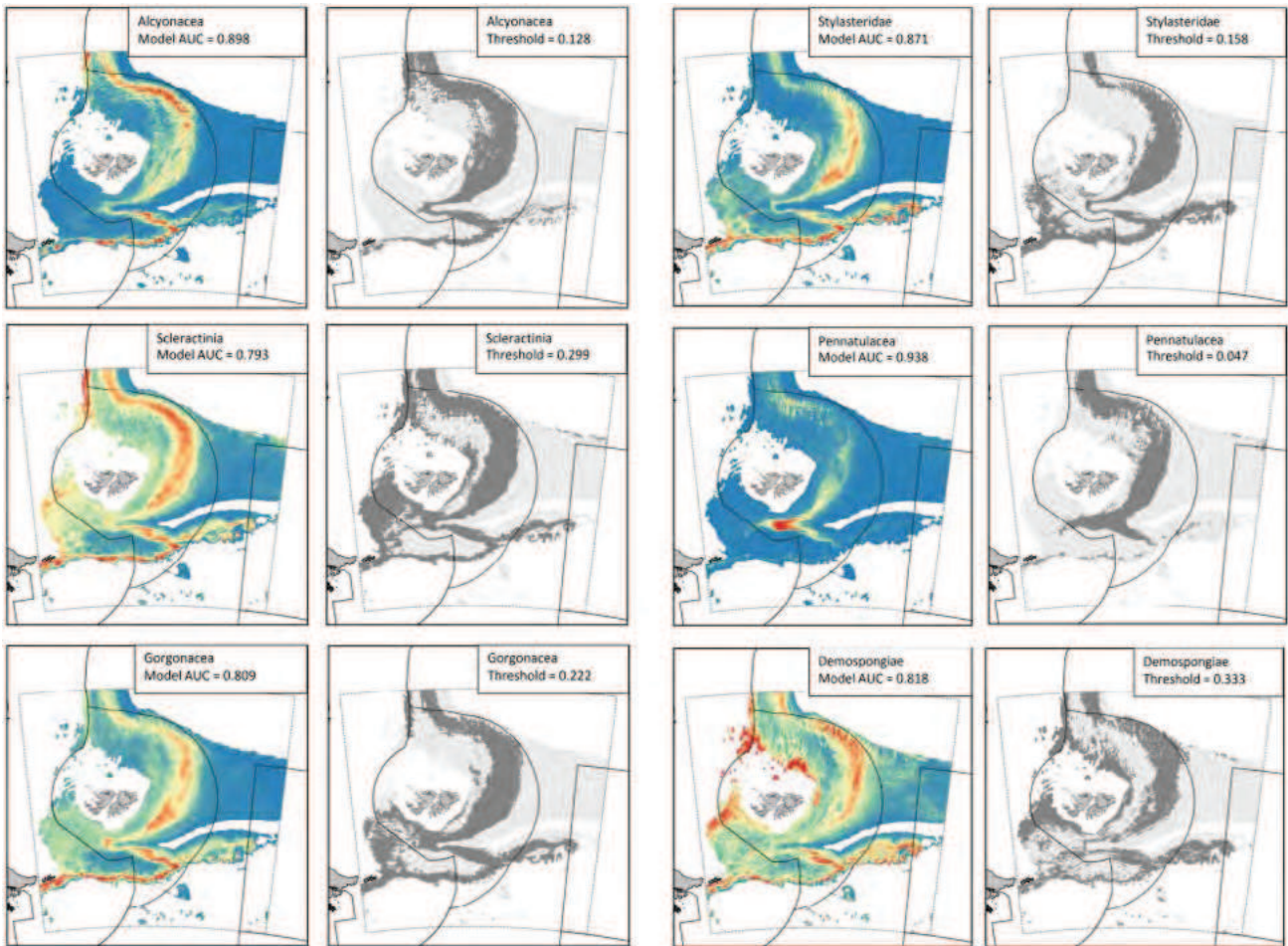


**Fig. 2.2:** VME indicator taxa examples showing the range of species and patchiness (a) Soft sediment dominated by sea pens; (b) various coral species and a stalked crinoid; (c) coral reef-like habitat; (d) VME indicator taxa on rock patches; (e) down-line with weight adjacent to rock patch with large 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 occurrences	Proportion of observations (%)
<b>Scleractinia</b>	<b>CSS</b>	<b>Stony corals</b>	<b>362</b>	<b>23.1</b>
<b>Gorgonacea</b>	<b>GGW</b>	<b>Sea fans, Sea whips</b>	<b>242</b>	<b>15.4</b>
<b>Alcyonacea</b>	<b>AJZ</b>	<b>Soft corals</b>	<b>124</b>	<b>7.9</b>
<b>Pennatulacea</b>	<b>NTW</b>	<b>Sea pens</b>	<b>87</b>	<b>5.5</b>
Anthoathecatae	AZN	Hydroids	47	3.0
<b>Stylasteridae</b>	<b>AXT</b>	<b>Hydrocorals</b>	<b>116</b>	<b>7.4</b>
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				
<b>Demospongiae</b>	<b>DMO</b>	<b>Sponges</b>	<b>135</b>	<b>8.6</b>
Hexactinellida	HXY	Glass sponges	34	2.2
Chordata	SSX	Sea squirts	57	3.6
Brachiopoda	BRQ	Lamp shells	25	1.6
Bryozoa	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 (chLa) 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	<i>Alcyonacea</i>	<i>Scleractinia</i>	<i>Gorgonacea</i>	<i>Stylasteridae</i>	<i>Demospongiae</i>	<i>Pennatulacea</i>
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 ChLa mean	2.5	4	3.1	1.8	8.5	0.1
SS ChLa 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<sup>2</sup>, 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<sup>2</sup>). 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<sup>2</sup>, 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<sup>2</sup>) 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<sup>2</sup>) and percentage of predicted habitat area. Source: Brewin et al. (2020)

VME Group	Predicted Habitat area (km <sup>2</sup> )	Fishery footprint within predicted habitat (km <sup>2</sup> )	Footprint as % of predicted habitat	Low effort fishing area (km <sup>2</sup> )	Low effort fishing as % of predicted habitat	Medium effort fishing area (km <sup>2</sup> )	Medium effort fishing as % of predicted habitat	High effort fishing area (km <sup>2</sup> )	High effort fishing as % of predicted habitat
<b>Footprint in the FCZ</b>									
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
<b>Footprint in the ABNJ</b>									
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](http://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.

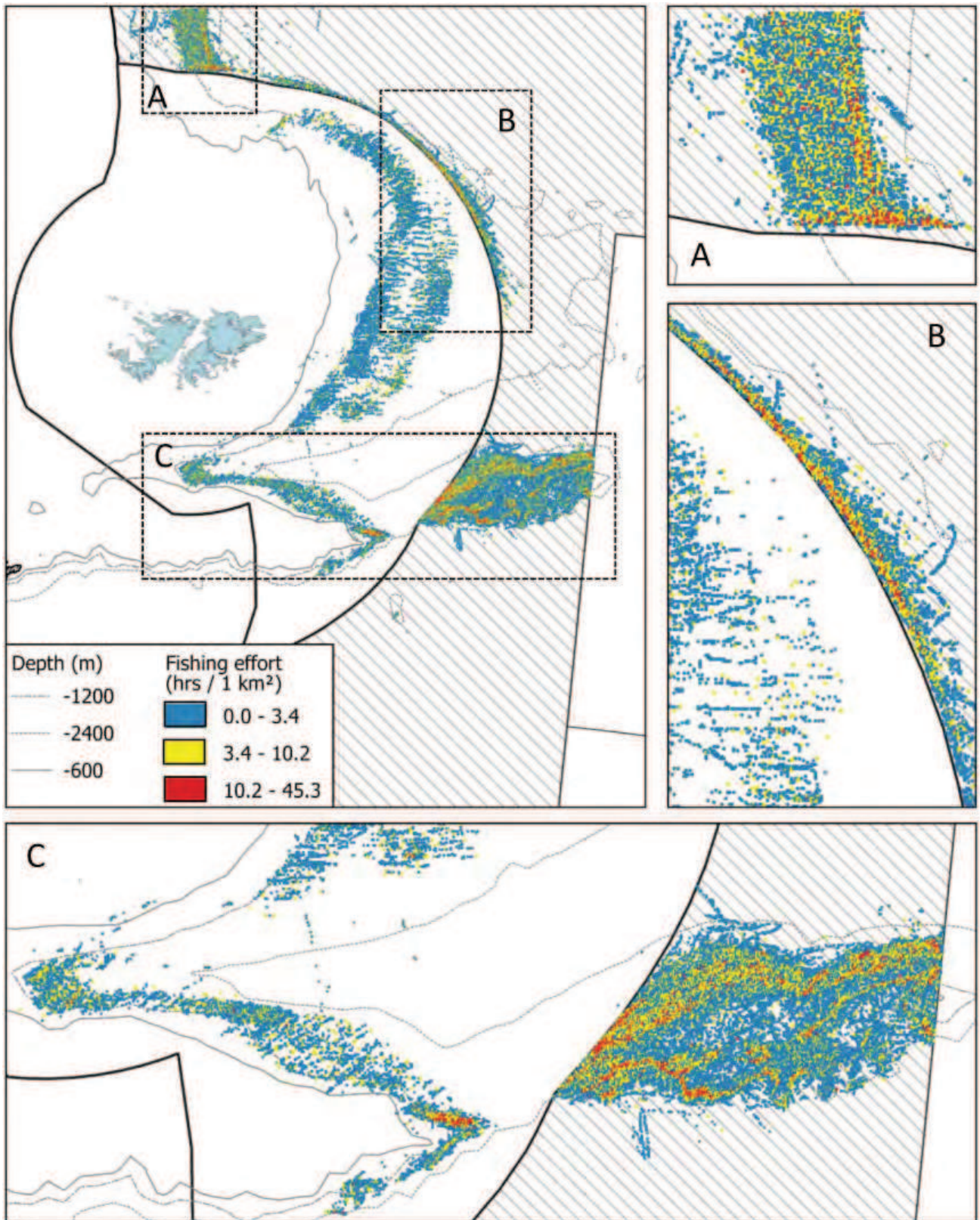
Brewin et al. (2020) outline that there are also other associated errors to consider such as “signal loss due to signal traffic, or gaps in the record due to satellite overpass times”. However, they ascertain, that in terms of GFW data itself, error rates for GFW predictions are low (Kroodsma et al. 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<sup>2</sup>) 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](http://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 validate 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; Hilarío 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

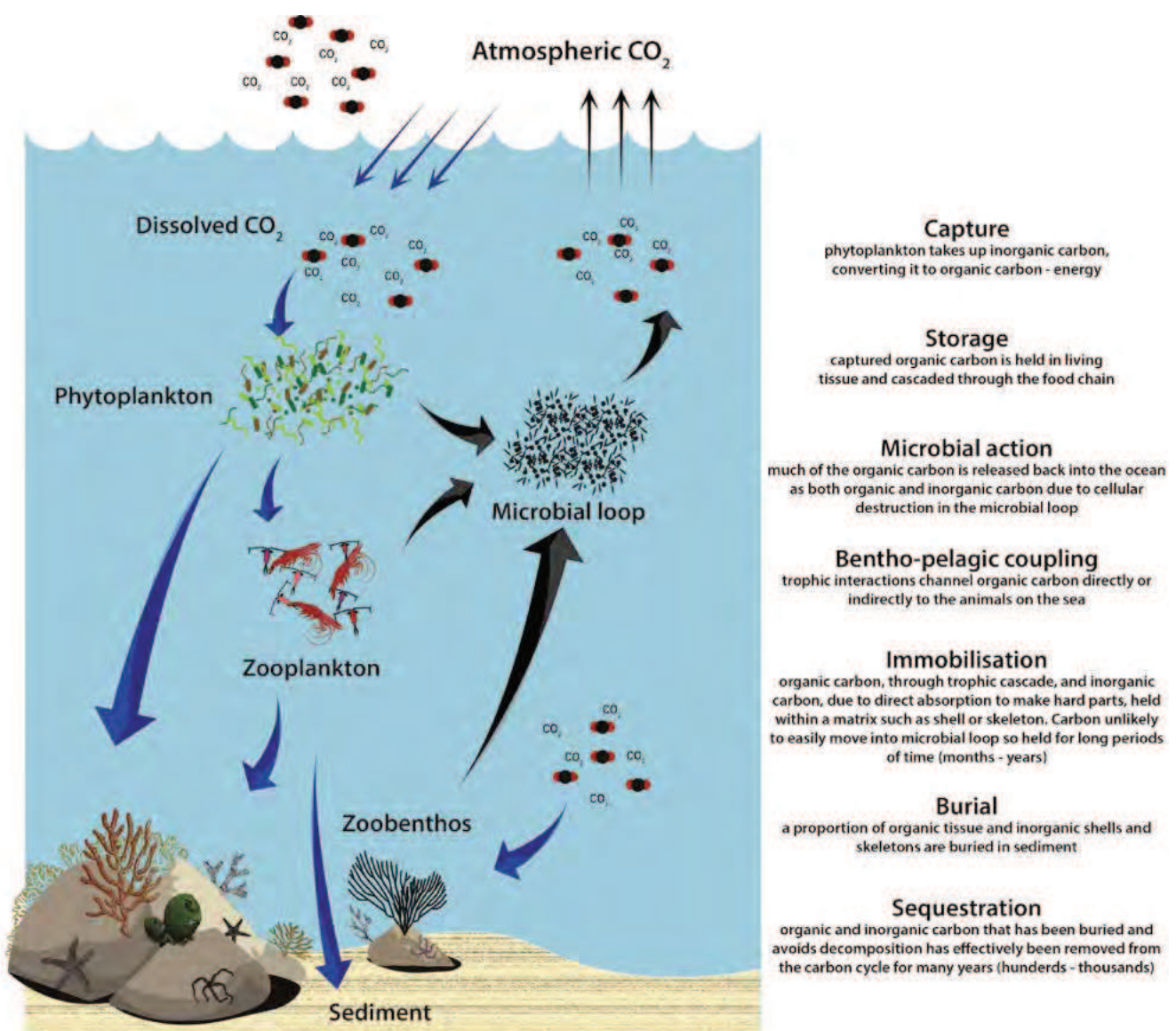
All Falkland Islands Government data used in Brewin et al., (2020) are available through the South Atlantic Environmental Research Institute (SAERI) IMG-GIS Data Centre. Data request forms and data management policies can be found through the website [www.south-atlantic-research.org/research/data-science](http://www.south-atlantic-research.org/research/data-science). 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 (SUCCS) imagery and (where possible) data from collected specimens in the context of VMEs and seafloor blue carbon.



**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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> IN THE MICROBIAL LOOP?

Organic carbon fuels marine food webs, transporting CO<sub>2</sub> 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<sub>2</sub>. If this release of carbon is greater than the uptake of carbon by phytoplankton, CO<sub>2</sub> 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<sub>2</sub> when building their CaCO<sub>3</sub> 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<sup>2</sup>.

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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> than they store during CaCO<sub>3</sub> 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<sub>2</sub> 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

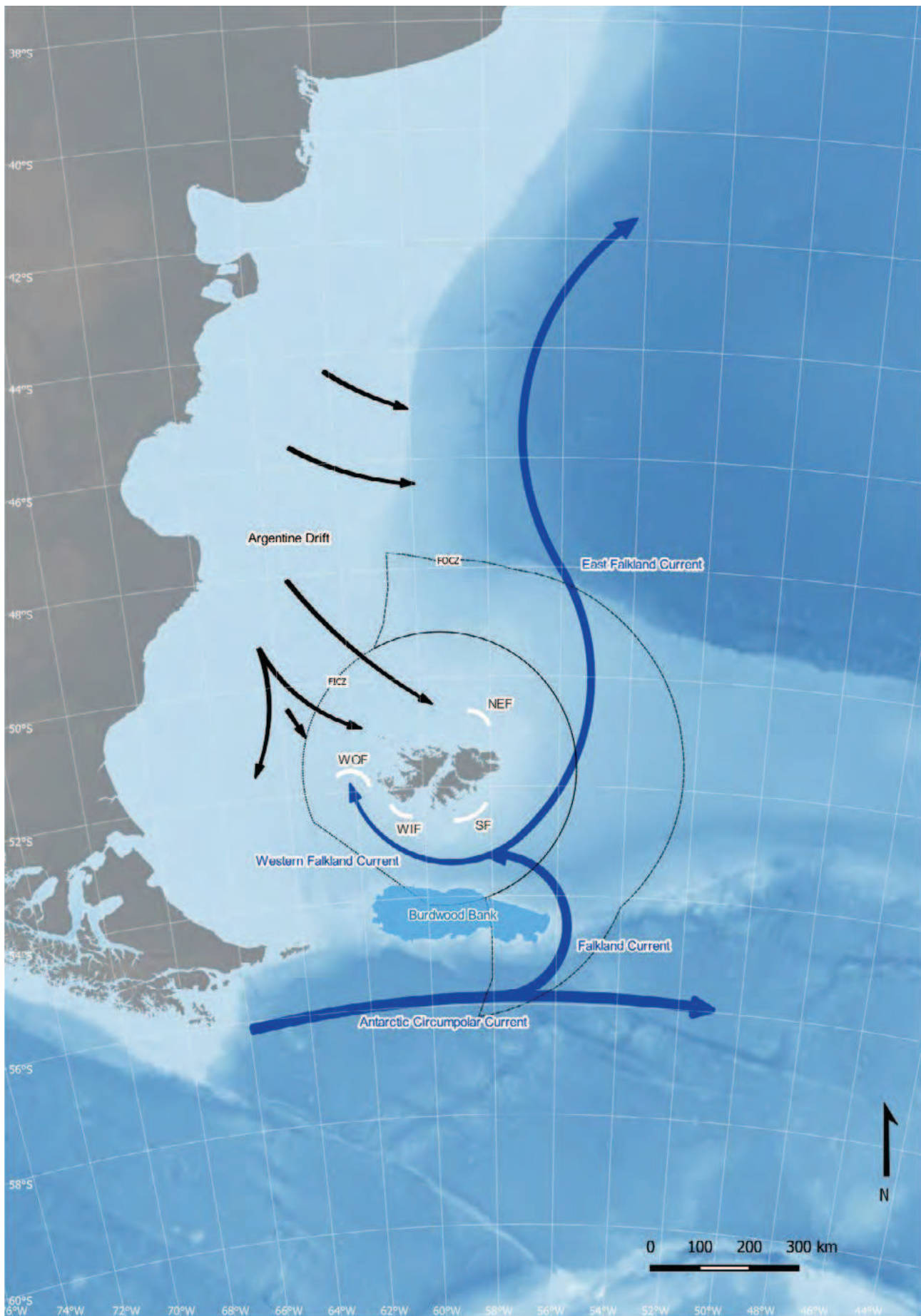
### Ecological setting

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.

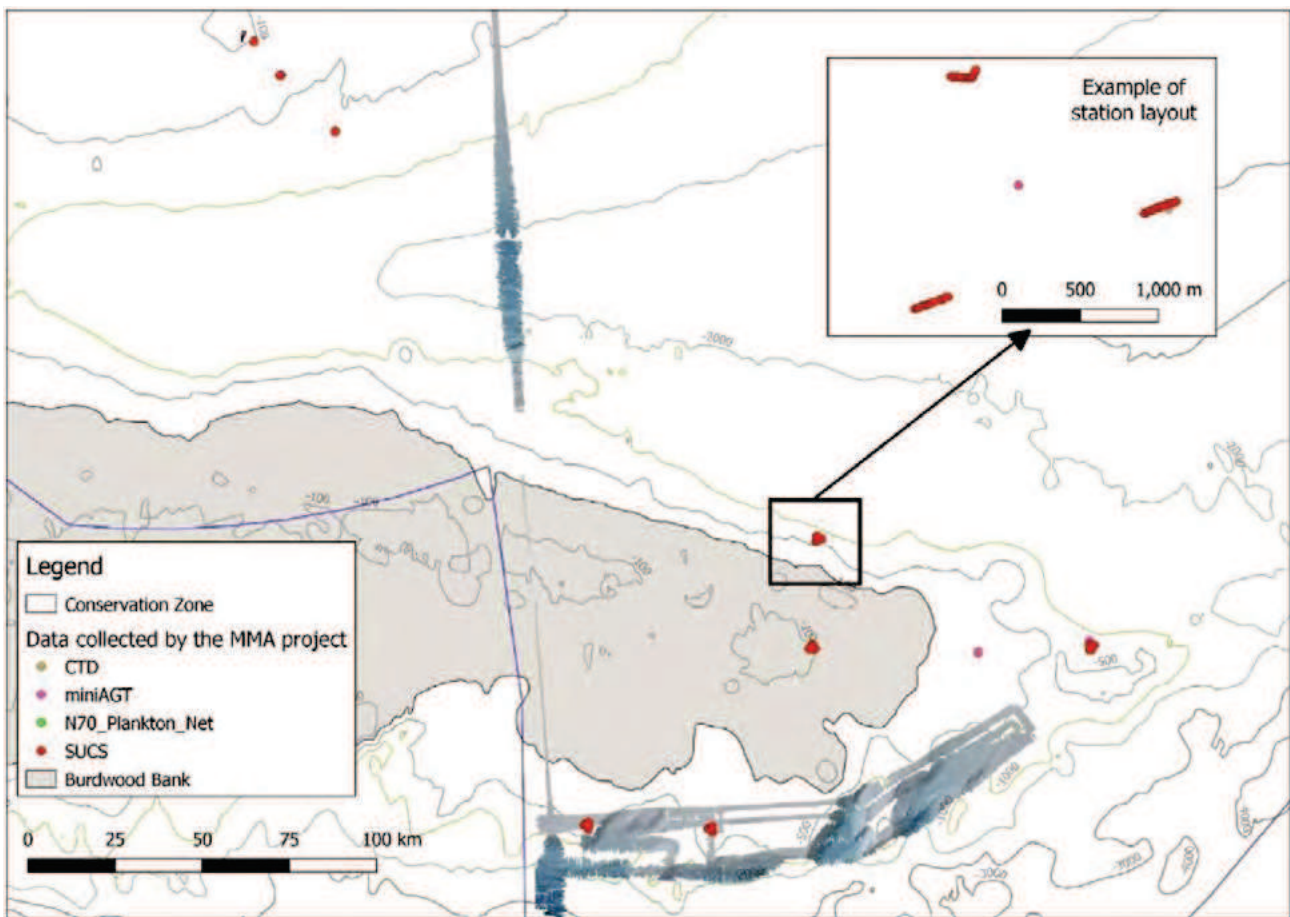
### Data collection

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.

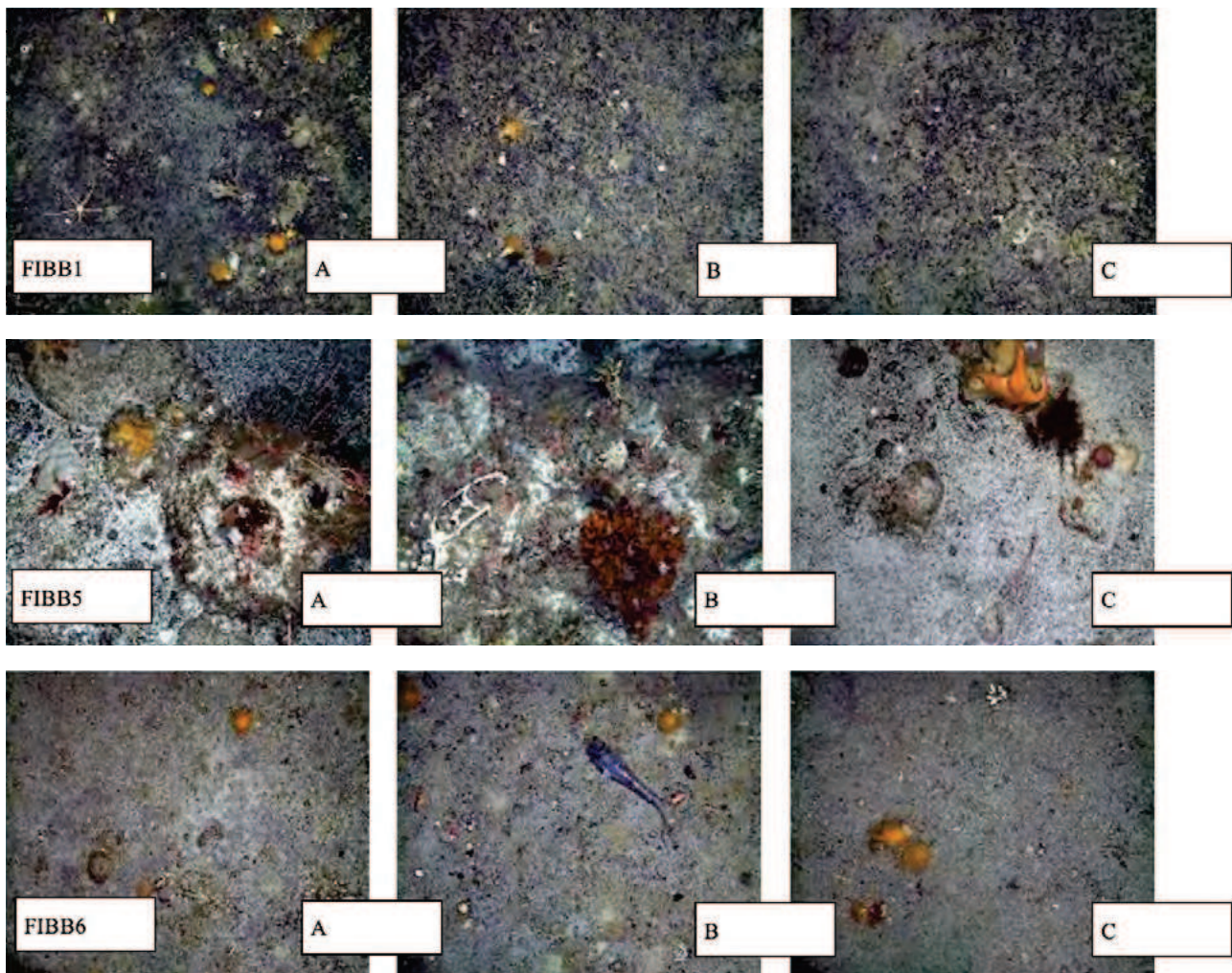


Fig. 2.8. Example of SUCS images on the Burdwood Bank.

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

Sequestration route	Carbon year <sup>-1</sup>
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, spiculans
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<sup>2</sup> (t zC/ km<sup>2</sup>) (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).

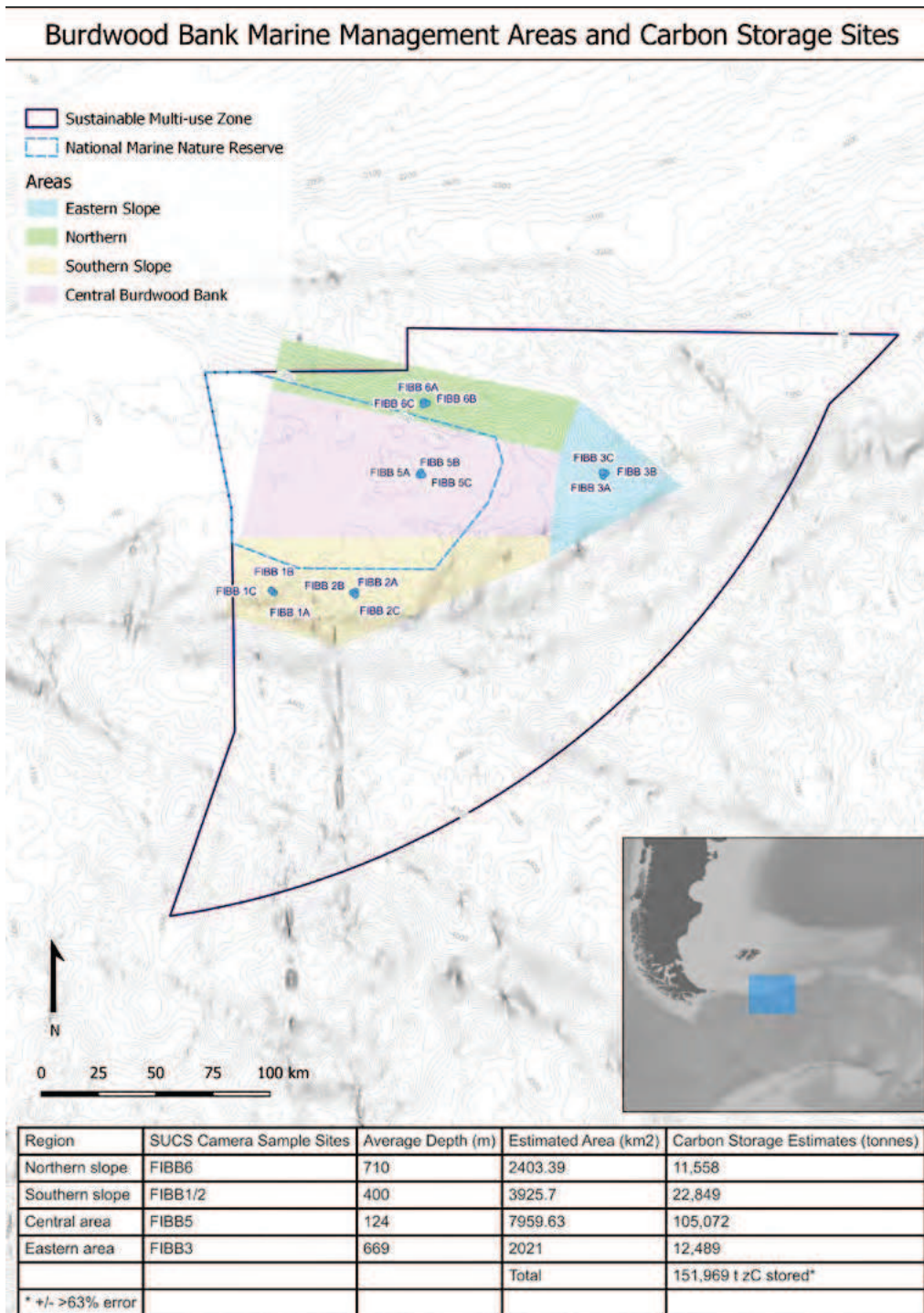
**Table 2.7.** VME taxa specimen collections were grouped into phylum to provide an overview of diversity sampled at each station on the Burdwood Bank. Bryozoans and cnidarians account for the highest percentage.

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

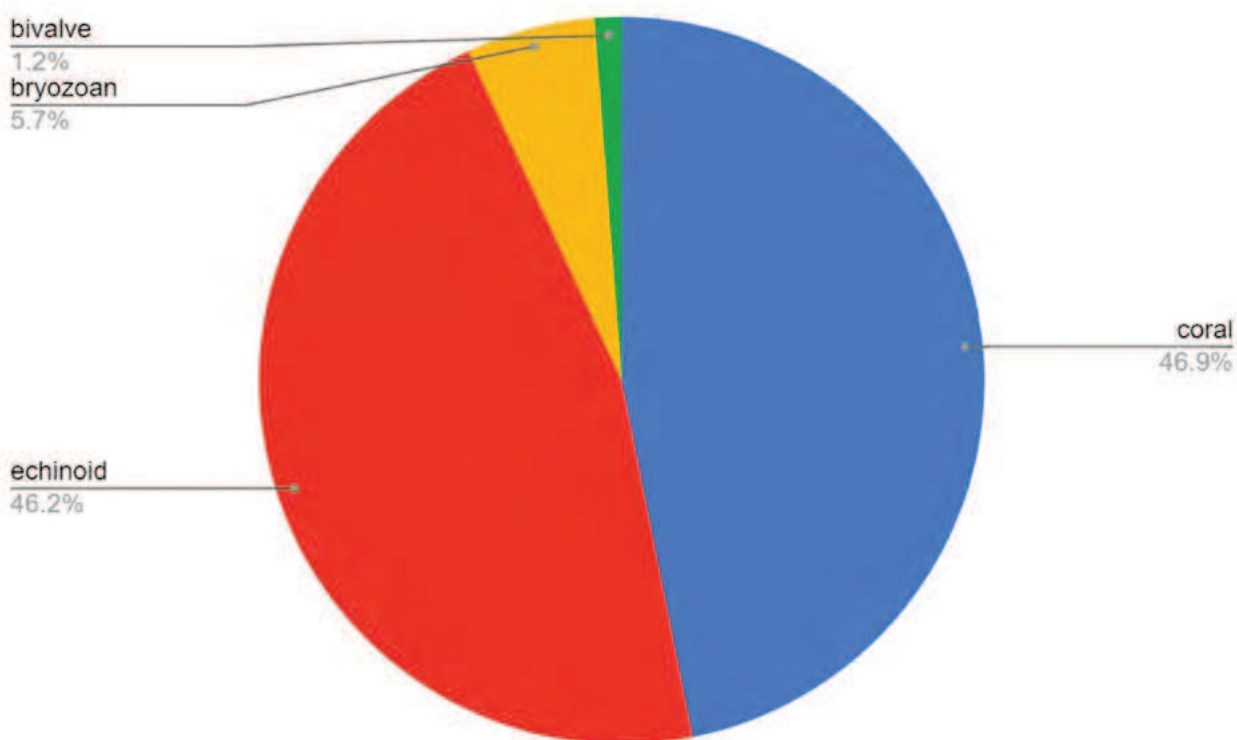
to Carbon dioxide equivalents in millions of tonnes of carbon and scaled to inform tonnes of yearly zoobenthic carbon per km<sup>2</sup> (t zC/ km<sup>2</sup>) (Table 2.8) using the method of Barnes et al. (2020). These preliminary estimates provide justification for future work in this area, especially 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).



**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 km <sup>2</sup>	Area km <sup>2</sup>	CO <sub>2</sub> equiv in million tonnes	Data Source
<b>Tropical</b>	Ascension	83	328.5	0.022	Barnes et al. 2019
	associated seamounts	61	282	0.015	Barnes et al. 2019
<b>Temperate</b>	Tristan da Cunha & Gough	201	1253	0.13	Barnes et al. 2021
	associated seamounts	274	7288	0.68	Barnes et al. 2021
<b>Temperate/ Sub-Antarctic</b>	Burdwood bank	*9.3	16310	0.56	Bax et al. Unpublished data in prep
<b>Antarctic</b>	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<sup>2</sup> (t zC/km<sup>2</sup>) (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 Zwierschke 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., stony 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 Burdwood 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 Burdwood 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 Burdwood 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 standardised 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 Burdwood 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 Burdwood 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 Burdwood 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

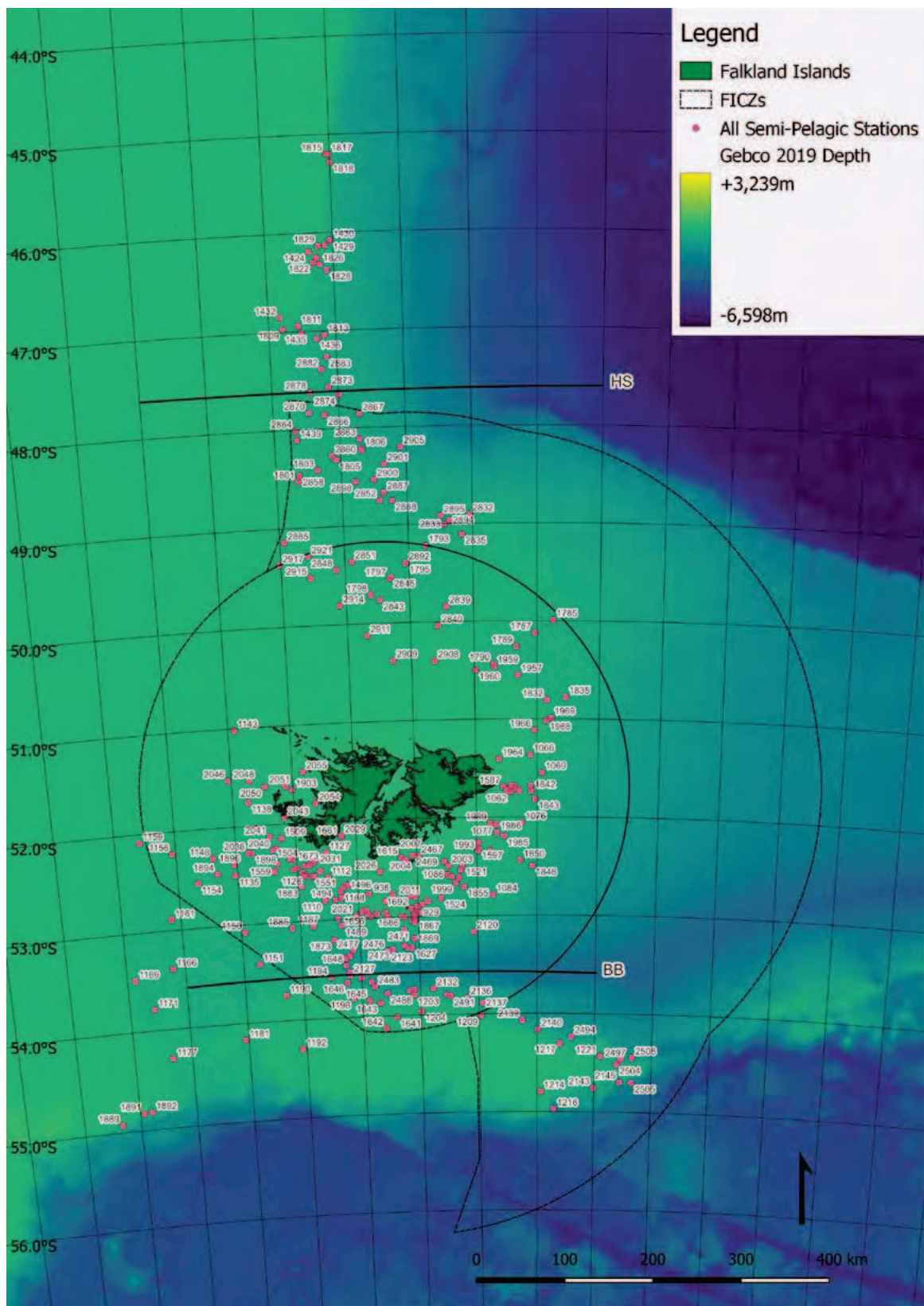
### Sampling

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

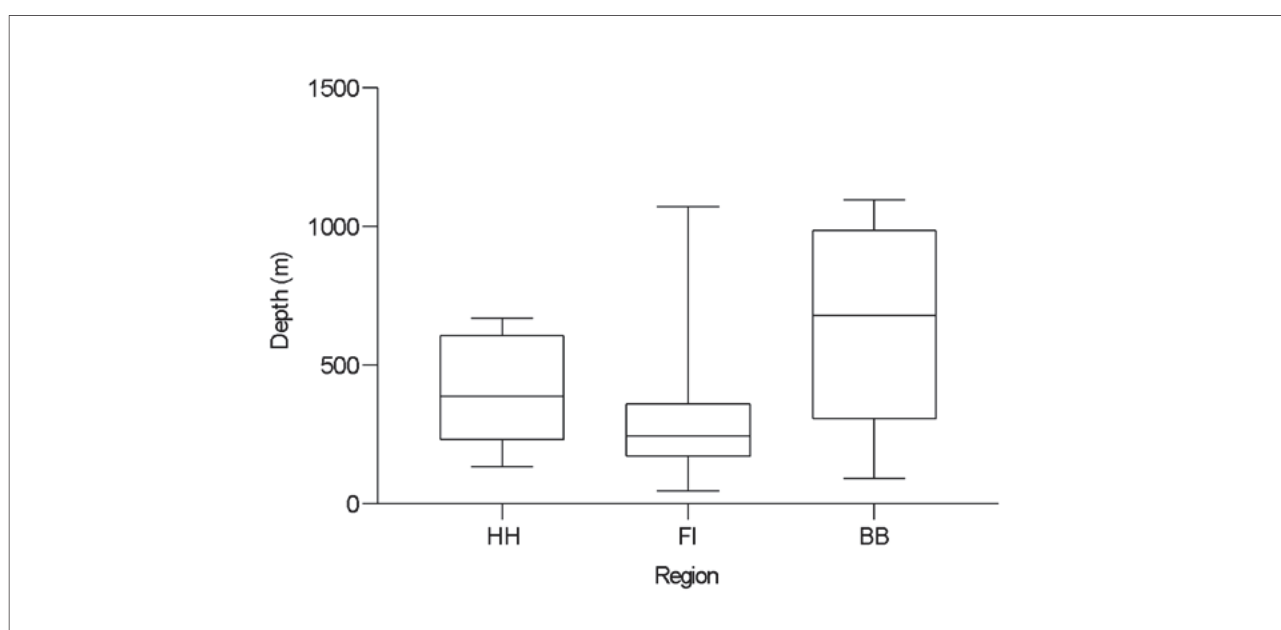
Species accumulation curves using Chao-2 and observed number of species (Sobs) estimators, with standard deviation, were produced in order to assess sampling effort based on faunal species occurrence data collected (Chao et al. 2009). A log (n+1) transformation was used on CPUEs of taxa encountered by 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	<i>Micromesistius australis</i>	Gadiformes	Gadidae	41898.4368
Fish	<i>Macruronus magellanicus</i>	Gadiformes	Merlucciidae	26765.9248
Fish	<i>Macrourus carinatus</i>	Gadiformes	Macrouridae	8395.2158
Squid	<i>Doryteuthis (Amerigo) gahi</i>	Myopsida	Loliginidae	4057.0749
Squid	<i>Illex argentinus</i>	Oegopsida	Ommastrephidae	1757.1417
Fish	<i>Patagonotothen ramsayi</i>	Perciformes	Nototheniidae	999.1325
Fish	<i>Merluccius hubbsi</i>	Gadiformes	Merlucciidae	604.1765

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

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

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

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

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

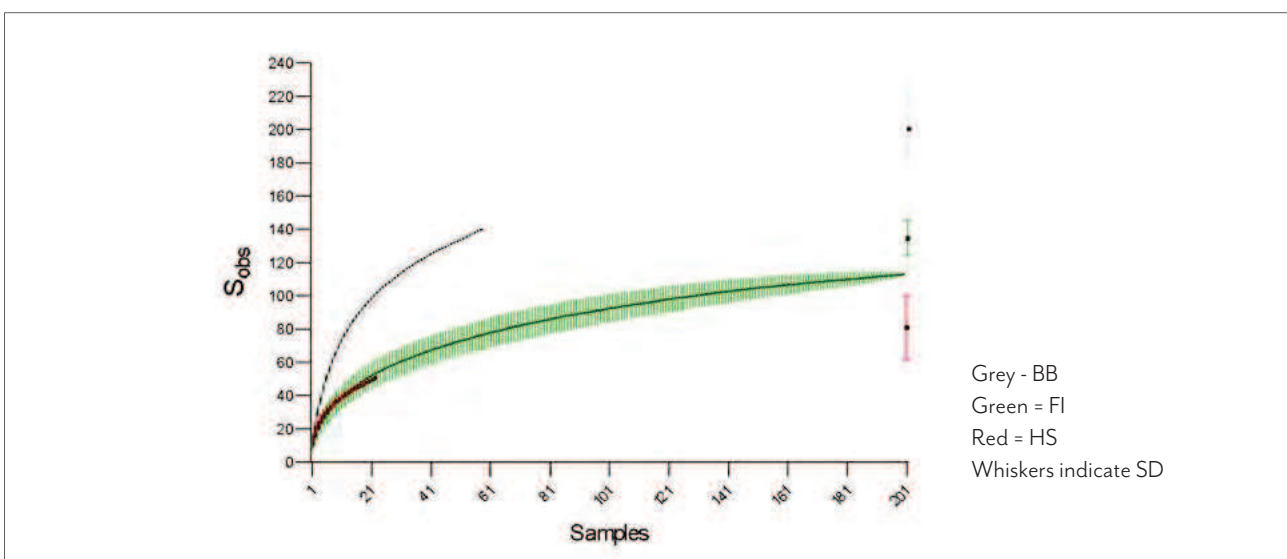
Group	ScientificName accepted	Order	Family	CPUE (kg/hr)
Fish	<i>Gymnoscopelus fraseri</i>	Myctophiformes	Myctophidae	0.0076
Fish	Stomiidae	Stomiiformes	Malacosteidae	0.0059
Fish	<i>Maurolicus muelleri</i>	Stomiiformes	Sternoptychidae	0.0055
Fish	<i>Metelectrona ventralis</i>	Myctophiformes	Myctophidae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



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

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

Species	BB	FI	HS
<i>Ceratias tentaculatus</i>	5.590024	0.090647	0
<i>Allothunnus fallai</i>	4.967742	10.16299	0
<i>Bathyraja papilionifera</i>	4.820567	0	0
<i>Bathyraja albomaculata</i>	4.613146	70.8389	6.097214
<i>Gymnoscopelus bolini</i>	4.218896	14.6404	3.729573
<i>Magnisudis prionosa</i>	2.920686	0.038915	0.220228
<i>Bathyraja scaphiops</i>	2.909268	22.39299	0
<i>Iluocoetes fimbriatus</i>	2.705414	6.02183	8.844712
<i>Lepidion ensiferus</i>	2.674791	0.127667	0
<i>Paradiplospinus gracilis</i>	2.671231	0.283203	0.027049
<i>Gymnoscopelus sp</i>	2.488401	9.216586	2.213016
<i>Bathyraja multispinis</i>	2.442545	17.16311	0
<i>Gymnoscopelus braueri</i>	2.429555	0.577963	0
<i>Mancopsetta milfordi</i>	2.372393	0	0
<i>Bathylagus antarcticus</i>	2.302403	0.136667	0
<i>Trigonolampa miriceps</i>	2.271372	0.087626	0
<i>Pseudocyttus maculatus</i>	2.239126	0	0
<i>Psychrolutes marmoratus</i>	2.198446	2.54014	0
<i>Patagonotothen guntheri</i>	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  $200.5 \pm 24.9$  indicating a much greater species diversity on the Burdwood Bank compared to the High Seas area and in the Falkland Island Conservation Zone.

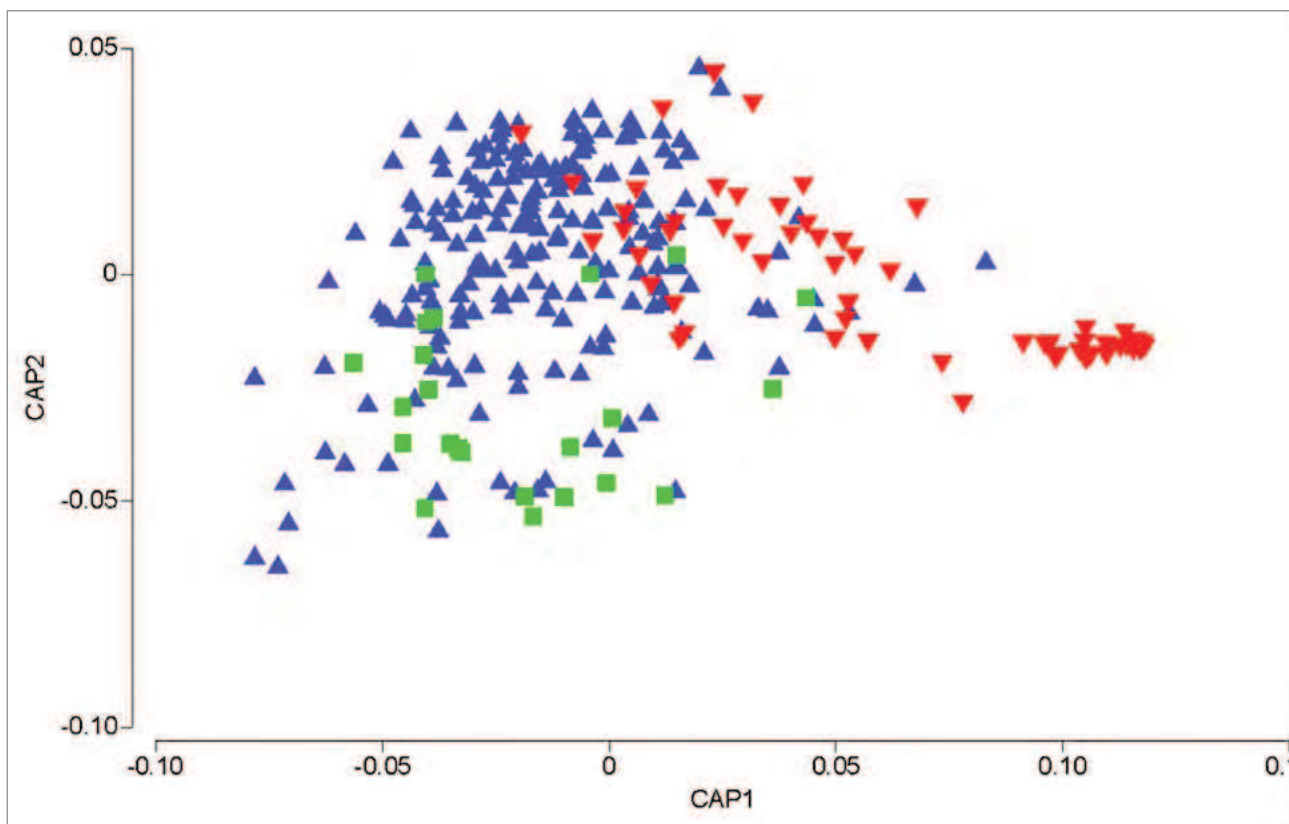
### Multivariate analyses

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.

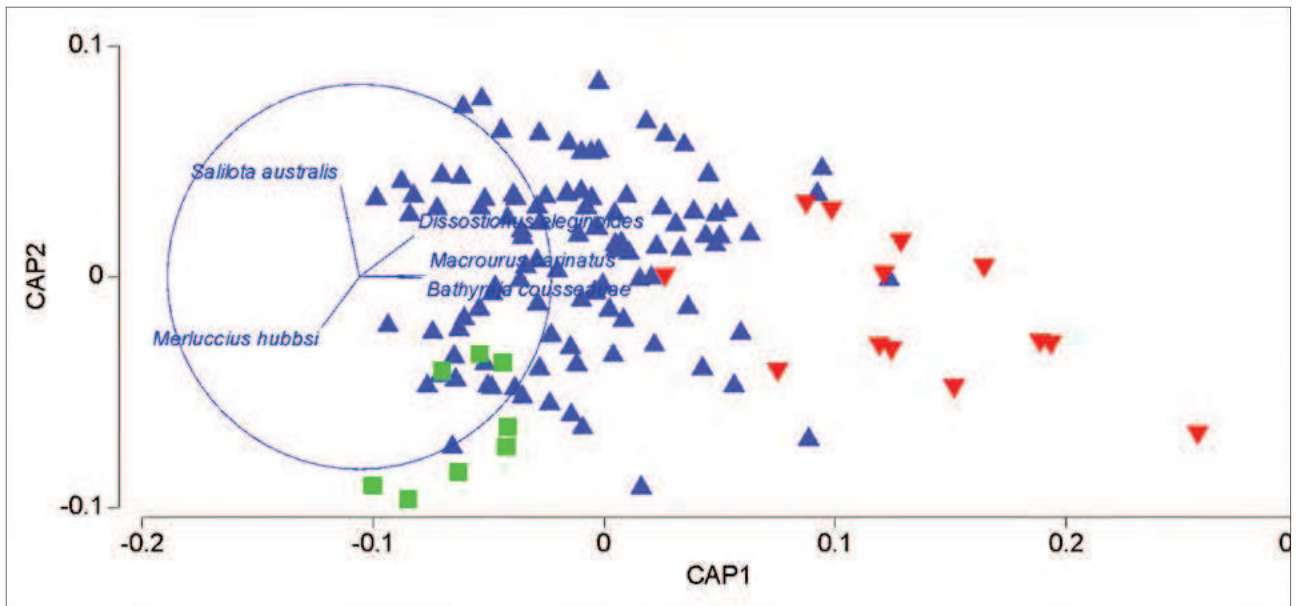
The separation of community structure becomes clearer when these are re analysed and compared between the depth strata (shelf and slope).

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

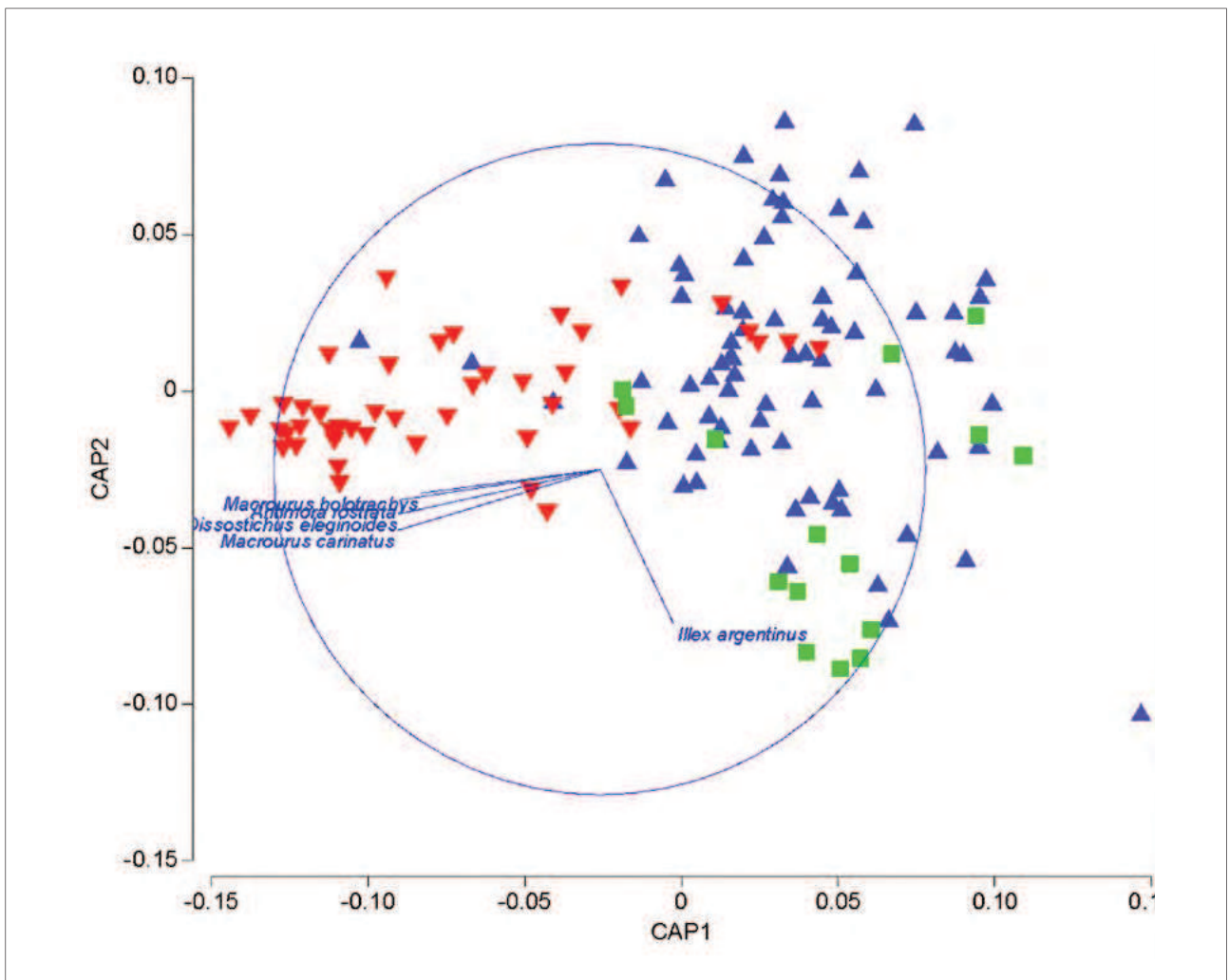
Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
De	1	29754	29754	4.3657	0.004	999
Ye	4	19144	4786.1	0.80673	0.774	996
Mo	4	16631	4157.7	0.71672	0.856	999
DexYe**	6	24442	4073.7	0.62283	0.8	998
DexMo**	5	23223	4644.7	0.77248	0.661	999
YexMo**	1	6892.8	6892.8	1.4417	0.266	980
DexYexMo**	2	10207	5103.6	2.32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

## REFERENCES

- Acha, E.M., H.W. Mianzan, R.A. Guerrero, M. Favero, Bava J. 2004. Marine fronts at the continental shelves of austral South America: Physical and ecological processes. *Journal of Marine Systems* 44: 83–105.
- Agnew, D.J. 2002. Critical aspects of the Falkland Islands pelagic ecosystem: distribution, spawning and migration of pelagic animals in relation to oil exploration. *Aquatic Conservation* 12, 39–50.
- Aleman, D., E.M. Acha, Iribarne O. 2009. The relationship between marine fronts and fish diversity in the Patagonian Shelf large marine ecosystem. *Journal of Biogeography* 36: 2111– 2124.
- Amoroso RO, Pitcher CR, Rijnsdorp AD, McConnaughey RA, Parma AM, Suuronen P, Eigaard OR, Bastardie F, Hintzen NT, Althaus F, Baird SJ. 2018. Bottom trawl fishing footprints on the world's continental shelves. *Proceedings of the National Academy of Sciences*. 2018 Oct 23;115(43):E10275-82.
- Anderson, O. F., Guinotte, J. M., Rowden, A. A., Clark, M. R., Mormede, S., Davies, A. J., and Bowden, D. A. 2016a. Field validation of habitat suitability models for vulnerable marine ecosystems in the South Pacific Ocean: implications for the use of broad-scale models in fisheries management. *Ocean and Coastal Management*, 120: 110–126.
- Anderson, O. F., Guinotte, J. M., Rowden, A. A., Tracey, D. M., Mackay, K. A., Clark, M. R. 2016b. Habitat suitability models for predicting the occurrence of vulnerable marine ecosystems in the seas around New Zealand. *Deep-Sea Research Part I*, 115: 265–292.
- Anderson, M.J., Gorley R.N., Clarke, K.R. 2008. PERMANOVA+ for PRIMER: guide to software and statistical methods. PRIMER-E, Plymouth
- Ardron, J.A., Clark, M.R., Penney, A.J., Hourigan, T.F., Rowden, A.A., Dunstan, P.K., Watling, L., Shank, T.M., Tracey, D.M., Dunn, M.R., Parker, S.J., 2014. A systematic approach towards the identification and protection of vulnerable marine ecosystems. *Marine Policy*, 49, pp.146-154.
- Arhan, M., Naveira Garabato, A. C., Heywood, K. J., Stevens, D. P. 2002. The Antarctic Circumpolar Current between the Falkland Islands and South Georgia. *Journal of Physical Oceanography*, 32: 1914–1931.
- Arkhipkin, A.I. and Laptikhovsky, V.V., 2010. Convergence in life-history traits in migratory deep-water squid and fish. *ICES Journal of Marine Science*, 67(7), pp.1444-1451.
- Arkhipkin, A., P. Brickle and V. Laptikhovsky 2013. Links between marine fauna and oceanic fronts on the Patagonian Shelf and Slope. *Arquipelago. Life and Marine Sciences* 30: 19-37.
- Auster, P.J., Gjerde, K., Heupel, E., Watling, L., Grehan, A., Rogers, A.D. 2011. Definition and detection of vulnerable marine ecosystems on the high seas: problems with the “move-on” rule. *ICES J. Mar. Sci.* 68(2), 254-264. doi:10.1093/icesjms/fsq074.
- Barnes, D.K.A. 2015 Antarctic sea ice losses drive gains in benthic carbon drawdown. *Curr. Biol.* 25(18), R789-R790. doi:10.1016/j.cub.2015.07.042.
- Barnes, D.K.A., and Sands, C.J. 2017. Functional group diversity is key to Southern Ocean benthic carbon pathways. *PLoS One* 12(6), 1-14. doi:10.1371/journal.pone.0179735.

- Barnes, D.K., Fleming, A., Sands, C.J., Quartino, M.L. and Deregiibus, D., 2018. Icebergs, sea ice, blue carbon and Antarctic climate feedbacks. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 376(2122), p.20170176.
- Barnes, D.K., Morley, S.A., Bell, J., Brewin, P., Brigden, K., Collins, M., Glass, T., Goodall-Copestake, W.P., Henry, L., Laptikhovsky, V., Piechaud, N. 2018. Marine plastics threaten giant Atlantic marine protected areas. *Current Biology*, 28(19), pp.R1137-R1138.
- Barnes, D. K., Sands, C. J., Richardson, A., Smith, N. 2019. Extremes in benthic ecosystem services; blue carbon natural capital shallower than 1000 m in isolated, small, and young Ascension Island's EEZ. *Frontiers in Marine Science*, 663.
- Barnes, D.K., Bell, J.B., Bridges, A.E., Ireland, L., Howell, K.L., Martin, S.M., Sands, C.J., Mora Soto, A., Souster, T., Flint, G., Morley, S.A. 2021. Climate mitigation through biological conservation: Extensive and valuable blue carbon natural capital in Tristan da Cunha's giant Marine Protected Zone. *Biology*, 10(12), p.1339.
- Bayley, D.T.I., Brickle, P., Brewin, P.E., Golding, N., and Pelembe, T. 2021. Valuation of kelp forest ecosystem services in the Falkland Islands: A case study integrating blue carbon sequestration potential. *One Ecosystem*. 6, e62811. doi:10.3897/oneeco.6.e62811.
- Baylis, A. M. M., de Lecea, A. M., Tierney, M., Orben, R. A., Ratcliffe, N., Wakefield, E., et al. Overlap between marine predators and proposed Marine Managed Areas on the Patagonian Shelf. *Ecol. Appl.*
- Bax, N., and Cairns, S. D. 2014. Stylasteridae (Cnidaria; Hydrozoa). *Biogeographic atlas of the southern ocean*.
- Bax, N., Sands, C.J., Gogarty, B., Downey, R.V., Moreau, C.V.E., Moreno, B., et al. 2021. Perspective: Increasing blue carbon around Antarctica is an ecosystem service of considerable societal and economic value worth protecting. *Glob. Change Biol.* 27(1), 5-12. doi:10.1111/gbc.15392.
- Bax, N., S.E.A. Pineda-Metz, T. Pearman, M. Dising, S. Carter, R. Downey, C.D Evans, D.K.A Barnes, P. Brickle, A. Baylis, A. Adler, A. Guest, K.A. Layton, P. B Brewin and D.T.I Bayley (in review) Incorporating blue carbon in Falkland Islands marine spatial planning: a multi-tiered approach. *Frontiers in Marine Science*.
- Brasier, M.J., Barnes, D., Bax, N., Brandt, A., Christianson, A.B., Constable, A.J., Downey, R., Figuerola, B., Griffiths, H., Gutt, J. and Lockhart, S., 2021. Responses of Southern Ocean seafloor habitats and communities to global and local drivers of change. *Frontiers in Marine Science*, 8, p.109.
- Belkin, I.M., Cornillon, P.C. and Sherman, K., 2009. Fronts in large marine ecosystems. *Progress in Oceanography*, 81(1-4), pp.223-236.
- Bianchi, A., 1982. Analisis estadístico de las características TS del sector austral de la Plataforma Continental Argentina. *Acta Oceanog. Arg.*, 3, pp.93-118.
- Boltovskoy, D., ed. 2000. *South Atlantic zooplankton*. Backhuys Publishers, Leiden, 1706 pp.
- 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.
- Brey, T., and Gerdes, D. 1999. Benthic community productivity in the Magellan region and in the Weddell Sea. *Sci. Mar.* 63(1), 145-148.
- Brown, J., Brickle, P., Hearne, S., and French, G. 2010. An experimental investigation of the 'umbrella' and Spanish' system of longline fishing for the Patagonian toothfish (*Dissostichus eleginoides*) in the Falkland Islands: implications for stock assessment and seabird by-catch. *Fisheries Research*, 106: 404-412.
- Borja, A., Elliott, M., Snelgrove, P. V. R., Austen, M. C., Berg, T., Cochrane, S., Carstensen, J., et al. 2016. Bridging the gap between policy and science in assessing the health status of marine ecosystems. *Frontiers in Marine Science*, 3: 175.

- Bormpoudakis D, Fish R, Guest A, Smith N. 2019. South Atlantic Natural Capital Assessment: Cultural Ecosystem Services in the Falkland Islands.
- Burke, A., and Robinson, L. F. 2012. The Southern Ocean's role in carbon exchange during the last deglaciation. *science*, 335(6068), 557-561.
- Cairns, S.D., and Polonio, V. 2013 New records of deep-water Scleractinia off Argentina and the Falkland Islands. *Zootaxa* 3691(1), 58-86. doi:10.11646/zootaxa.3691.1.2.
- Carranza, A., Limongi, P., and Schmidt-Rhaesa, A. 2022. Benthic invertebrates collected by the RV 'Walther Herwig I and II' in the Southwestern Atlantic Ocean (1966-1978): A review of the invertebrates collection of the Zoological Museum of Hamburg. *Marine and Fishery Sciences (MAFIS)*, 35(1), 115-122.
- Clark, M. R., Althaus, F., Schlacher, T. A., Williams, A., Bowden, D. A., and Rowden, A. A. 2016. The impacts of deep-sea fisheries on benthic communities: a review. *ICES Journal of Marine Science*, 73: i51-i69.
- Clark, M. R., Tittensor, D., Rogers, A. D., Brewin, P., Schlacher, T., Rowden, A., and Stocks, K. 2006. Seamounts, Deep-Sea Corals and Fisheries: Vulnerability of Deep-Sea Corals to Fishing on Seamounts beyond Areas of National Jurisdiction. UNEP-WCMC, Cambridge, UK. Collins, M. A., Brickle, P., Brown, J., and Belchier, M. 2010. The Patagonian toothfish: biology, ecology and fishery. *Advances in Marine Biology*, 58: 227-300.
- Coastal Carbon Atlas <https://ccrcn.shinyapps.io/CoastalCarbonAtlas/> [accessed 16.02.2022]
- Cousseau, M. B., Pequeño, G., Mabragaña, E., Lucifora, L. O., Martínez, P. and Giussi, A. 2019. The Magellanic Province and its fish fauna (South America): Several provinces or one? *Journal of Biogeography*. 47: 220-234.
- Csirke, J. 1987. The Patagonian fishery resources and the offshore fisheries in the South-West Atlantic. *FAO Fisheries Technical Paper* 286, 75 pp.
- Davies, A. J., and Guinotte, J. M. 2011. Global habitat suitability for framework-forming cold-water corals. *PLoS One*, 6: e18483.
- De Broyer, C. and Koubbi, P. eds., 2014. *Biogeographic atlas of the Southern Ocean* (p. 498). Cambridge: Scientific Committee on Antarctic Research.
- Doti, B. L., Chiesa, I. L., & Roccatagliata, D. 2020. Biodiversity of Isopoda and Cumacea (Peracarida, Crustacea) from the Marine Protected Area Namuncurá-Burdwood Bank, South-West Atlantic. *Polar Biology*, 43(10), 1519-1534.
- Dunn, D. C., Jablonicky, C., Crespo, G. O., McCauley, D. J., Kroodsmá, D. A., Boerder, K., Gjerde, K. M., et al. 2018. Empowering high seas governance with satellite vessel tracking data. *Fish and Fisheries*, 19: 729-739. EC. 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). *Official Journal of the European Union*, 164: 19-40. <http://data.europa.eu/eli/dir/2008/56/oj> (last accessed 26 June 2020).
- FAO. 2008. *International Guidelines for the Management of Deep-Sea Fisheries in the High-Seas*. Food and Agriculture Organization of the United Nations. Adopted in Rome, Italy on 29 August 2008.
- FAO. 2016. *Vulnerable Marine Ecosystems: Processes and Practices in the High Seas*. Ed. by A. Thompson, J. Sanders, M. Tandstad, F. Carocci and J. Fuller. *FAO Fisheries and Aquaculture Technical Paper* 595. Rome, Italy.
- Farrugia, T. J., Goyot, L., and Kuepfer, A. 2018. *Scientific Report, Fisheries Cruise ZDLK3-11-2018*. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. Farrugia, T. J., and Keningale, B. 2018. *Scientific Report, Fisheries Cruise ZDLK3-02-2018*. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands.

- Fourcade, Y., Engler, J. O., Rödder, D., and Secondi, J. 2014. Mapping species distributions with MAXENT using a geographically biased sample of presence data: a performance assessment of methods for correcting sampling bias. *PLoS One*, 9: e97122.
- Franco, B.C., A.R. Piola, A.L. Rivas, A. Baldoni & J.P. Pisoni 2008. Multiple thermal fronts near the Patagonian Shelf break. *Geophysical Research Letters* 35: L02607.
- Gogarty, B., McGee, J., Barnes, D.K., Sands, C.J., Bax, N., Haward, M., Downey, R., Moreau, C., Moreno, B., Held, C. and Paulsen, M.L. 2020. Protecting Antarctic blue carbon: as marine ice retreats can the law fill the gap?. *Climate Policy*, 20(2), pp.149-162.
- Guerrero, R. A., Baldoni, A., & Benavides, H. 1999. Oceanographic conditions at the southern end of the Argentine continental slope. *INIDEP Doc. Cient.*, 5, 7–22. Contribution 1083.
- Guillaumot, C., Martin, A., Ele´aume, M., and Sauce`de, T. 2018. Methods for improving species distribution models in data-poor areas: example of sub-Antarctic benthic species on the Kerguelen Plateau. *Marine Ecology Progress Series*, 594: 149–164.
- Greathead, C., Gonza´lez-Irusta, J. M., Clarke, J., Boulcott, P., Blackadder, L., Weetman, A., and Wright, P. J. 2014. Environmental requirements for three sea pen species: relevance to distribution and conservation. *ICES Journal of Marine Science*, 72: 576–586.
- Kaiser, S., Brandão, S.N., Brix, S., Barnes, D.K., Bowden, D.A., Ingels, J., Leese, F., Schiaparelli, S., Arango, C.P., Badhe, R. and Bax, N. 2013. Patterns, processes and vulnerability of Southern Ocean benthos: a decadal leap in knowledge and understanding. *Marine biology*, 160(9), pp.2295-2317.
- Figuerola, B., Hancock, A.M., Bax, N., Cummings, V.J., Downey, R., Griffiths, H.J., et al. 2021. A Review and Meta-Analysis of Potential Impacts of Ocean Acidification on Marine Calcifiers From the Southern Ocean. *Front. Mar. Sci.* 8, 584445. doi:10.3389/fmars.2021.584445.
- Halpern, B. S., Frazier, M., Potapenko, J., Casey, K. S., Koenig, K., Longo, C., Lowndes, J. S., et al. 2015. Spatial and temporal changes in cumulative human impacts on the world’s ocean. *Nature Communications*, 6: 7615.
- Halvorsen, R. 2013. A maximum likelihood explanation of MaxEnt, and some implications for distribution modelling. *Sommerfeltia*, 36: 1–132.
- Henry, L.-A., and Roberts, J. M. 2007. Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic. *Deep-Sea Res I*, 54: 654–672.
- Hiddink, J. G., Jennings, S., Sciberras, M., Szostek, C. L., Hughes, K. M., Ellis, N., Rijnsdorp, A. D., et al. 2017. Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. *Proceedings of the National Academy of Sciences of the United of America*, 114: 8301–8306. doi/10.1073/pnas. 1618858114.
- Hila´rio, A., Metaxas, A., Gaudron, S. M., Howell, K. L., Mercier, A., Mestre, N. C., Ross, R. E., et al. 2015. Estimating dispersal distances in the deep sea: challenges and application to marine reserves. *Frontiers in Marine Science*, 2: 1–14.
- Hogg, O. T., Huvenne, V., Griffiths, H. J., Dorschel, B., and Linse, K. 2016. Landscape mapping at sub-Antarctic South Georgia provides a protocol for underpinning large-scale marine protected areas. *Scientific Reports*, 6, doi 10.1038/srep33163
- Huston, M. A. 1999. Local processes and regional patterns: appropriate scales for understanding variation in the diversity of plants and animals. *Oikos*, 86: 393–401.
- IETA and the University of Maryland 2021. The Potential Role of Article 6 Compatible Carbon Markets in Reaching Net-Zero. [https://www.ieta.org/resources/Resources/Net-Zero/Final\\_Net-zero\\_A6\\_working\\_paper.pdf](https://www.ieta.org/resources/Resources/Net-Zero/Final_Net-zero_A6_working_paper.pdf) [Accessed February 7, 2022].

- Jenkins, C.J. 2019. dbSEABED: Information Integration System for Marine Substrates. <http://instaar.colorado.edu/~jenkinsc/dbseabed> [Accessed June 14, 2020].
- Jennerjahn, T.C. 2020. Relevance and magnitude of 'Blue Carbon' storage in mangrove sediments: Carbon accumulation rates vs. stocks, sources vs. sinks. *Estuarine, Coastal and Shelf Science*, 247, p.107027.
- Kenchington, E., Wang, Z., Lirette, C., Murillo, F. J., Guijarro, J., Yashayaev, I., and Maldonado, M. 2019. Connectivity modelling of areas closed to protect vulnerable marine ecosystems in the northwest Atlantic. *Deep Sea Research Part I*, 143: 85–103.
- Kinlan, B. P., Gaines, S. D., and Lester, S. E. 2005. Propagule dispersal and the scales of marine community process. *Diversity and Distributions*, 11: 139–148.
- Kramer-Schadt, S., Niedballa, J., Pilgrim, J. D., Schroder, B., Lindenborn, J., Reinfelder, V., Stillfried, M., et al. 2013. The importance of correcting for sampling bias in MaxEnt species distribution models. *Diversity and Distributions*, 19: 1366–1379.
- Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F., Wilson, A., et al. 2018. Tracking the global footprint of fisheries. *Science*, 359: 904–908.
- Laffoley, D., and Grimsditch, G.D. 2009. *The management of natural coastal carbon sinks*. Gland: SwissPrinters IRL.
- Laffoley, D., Baxter, J. M., Jewett, E. B., Brooks, M. T., & Lagos, N. A. 2021. *Ocean acidification: scientific understanding and challenges*. In *Research Handbook on Ocean Acidification Law and Policy*. Edward Elgar Publ.
- Laptikhovsky, V. V., Arkhipkin, A. I. & Brickle, P. 2008a. Biology and distribution of grenadiers of the family Macrouridae around the Falkland Islands. *American Fisheries Society Symposium* 63, 261–284.
- Laptikhovsky, V., Arkhipkin, A. and Brickle, P. 2008b. Life history, fishery and stock conservation of the Patagonian toothfish around the Falkland Islands. *American Fisheries Society Symposium* 49, 1357–1363.
- Lauvset, S. K., Key, R. M., Olsen, A., van Heuven, S., Velo, A., Lin, X., Schirnick, C. 2016. A new global interior ocean mapped climatology: the 11 GLODAP version 2. *Earth System Science Data*, 8: 325–340.
- Leibold, M. A., Holyoak, M., Mouquet, N., Amarasekare, P., Chase, J. M., Hoopes, M. F., Holt, R. D., et al. 2004. The metacommunity concept: a framework for multi-scale community ecology. *Ecology Letters*, 7: 601–613.
- Leichter, J. J., and Witman, J. D. 2009. Chapter 8. Basin-scale oceanographic influences on marine macroecological patterns. In *Marine Macroecology*, pp. 205–226. Ed. by J. D. Witman and K. Roy. University of Chicago Press, London. 442 pp.
- Liu, C., Berry, P. M., Dawson, T. P., and Pearson, R. G. 2005. Selecting thresholds of occurrence in the prediction of species distributions. *Ecography*, 28: 385–393.
- Lovrich, G. A., Romero, M. C., Tapella, F., and Thatje, S. 2005. Distribution, reproductive and energetic conditions of decapod crustaceans along the Scotia Arc (Southern Ocean). *Scientia Marina*, 69(2), 183-193.ishing.
- Marrari, M., Piola, A. R., and Valla, D. 2017. Variability and 20-year trends in satellite-derived surface chlorophyll concentrations in large marine ecosystems around south and western Central America. *Frontiers in Marine Science*, 4: 372.
- Matano, R. P., Palma, E. D. and Combes, V. 2019. The Burwood Bank Circulation. *Journal of Geophysical Research: Oceans*. 124 6904 – 6926.
- Mazloff, M. R., Heimbach, P., and Wunsch, C. 2010. An Eddy-Permitting Southern Ocean State Estimate. *Journal of Physical Oceanography*, 40: 880–899.

- MEA 2005. Millenium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis. Island Press.
- Merow, C., Smith, M. J., and Silander, J. A. A. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography*, 36: 1058–1069.
- Muñoz-Ramírez, P. D., Murillo, F. J., Sayago-Gil, M., Serrano, A., Laporta, M., Otero, I., and Gómez, C. 2011. Effects of deep-sea bottom longlining on the Hatton Bank fish communities and benthic ecosystem, north-east Atlantic. *Journal of the Marine Biological Association of the United Kingdom*, 91: 939–952.
- OSPAR. 2010. Background Document for Sea Pen and Burrowing Megafauna Communities. Biological Diversity and Ecosystems Series 481/2010. OSPAR Commission. [https://qsr2010.ospar.org/media/assessments/Species/POO481\\_Seapen\\_and\\_burrowing\\_megafauna.pdf](https://qsr2010.ospar.org/media/assessments/Species/POO481_Seapen_and_burrowing_megafauna.pdf).
- Parker, S. J., and Bowden, D. A. 2010. Identifying taxonomic groups vulnerable to bottom longline fishing gear in the Ross Sea region. *CCAMLR Science*, 17: 105–127.
- Pearman T. 2021 Habitats and Benthos Report. Marine Stewardship Council Audit.
- Peterson, R.G. and Whitworth T. III. 1989. The Subantarctic and Polar fronts in relation to deep water masses through the Southwestern Atlantic. *Journal of Geophysical Research* 94: 10817–10838.
- Piola, A. R., & Gordon, A. L. 1989. Intermediate waters in the southwest South Atlantic. *Deep Sea Research Part A: Oceanographic Research Papers*, 36(1), 1–16. [https://doi.org/10.1016/0198-0149\(89\)90015-0](https://doi.org/10.1016/0198-0149(89)90015-0) water squid and fish. *ICES Journal of Marine Science* 67, 1444–1451.
- Schejter, L., Rimondino, C., Chiesa, I., Díaz de Astarloa, J. M., Doti, B., Elías, R., Escolar, M., et al. 2016. Namuncurá Marine Protected Area: an oceanic hot spot of benthic biodiversity at Burdwood Bank, Argentina. *Polar Biology*, 39: 2373–2386.
- Schejter, L. and Albano Mariano. “Benthic communities at the marine protected area Namuncurá/Burdwood bank, SW Atlantic Ocean: detection of vulnerable marine ecosystems and contributions to the assessment of the rezoning process.” *Polar Biology* 44, no. 10: 2023–2037.
- Marrari, M., Piola, A. R., and Valla, D. 2017. Variability and 20-year trends in satellite-derived surface chlorophyll concentrations in large marine ecosystems around south and western Central America. *Frontiers in Marine Science*, 4: 372.
- Melbourne-Thomas, J., Audzijonyte, A., Brasier, M. J., Cresswell, K. A., Fogarty, H. E., Haward, M., and Pecl, G. T. 2021. Poleward bound: adapting to climate-driven species redistribution. *Reviews in fish biology and fisheries*, 1–21.
- Moyano G, H. I. 2005. Scotia Arc bryozoans from the LAMPOS expedition: a narrow bridge between two different faunas.
- Parker, S. J., and Bowden, D. A. 2010. Identifying taxonomic groups vulnerable to bottom longline fishing gear in the Ross Sea region. *CCAMLR Science*, 17: 105–127.
- Pham, C. K., Diogo, H., Menezes, G., Porteiro, F., Braga-Henriques, A., Vandeperre, F., and Morato, T. 2014. Deep-water longline fishing has reduced impact on Vulnerable Marine Ecosystems. *Scientific Reports*, 4: 4837.
- Phillips, S. J., Anderson, R. P., and Schapire, R. E. 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling*, 190: 231–259.
- Phillips, S. J., and Dudík, M. 2008. Modeling of species distribution with Maxent: new extensions and a comprehensive evaluation. *Ecography*, 31: 161–175.

- Robert, K., Jones, D. O. B., Roberts, J. M., and Huvenne, V. A. I. 2016. Improving predictive mapping of deep-water habitats: considering multiple model outputs and ensemble techniques. *Deep Sea Research Part I*, 113: 80–89.
- Roberts, C. M. 2002. Deep impact: the rising toll of fishing in the deep sea. *Trends in Ecology & Evolution*, 17: 242–245. Roberts, J. M., Wheeler, A. J., and Freiwald, A. 2006. Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science*, 312: 543–547.
- Rogers, A. D., Baco, A., Griffiths, H., and Hall-Spencer, J. M. 2007. Corals on seamounts. In *Seamounts: Ecology, Fisheries and Conservation*, pp. 141–169. Ed. by T. J. Pitcher, T. Morato, P. J. B. Hart, M. R. Clark, N. Haggan and R. S. Santos. Blackwell Publishing, Oxford.
- Rooper, C. N., Etnoyer, P. J., Stierhoff, K. L., and Olson, J. V. 2017. Effects of fishing gear on deep-sea corals and sponges in U.S. waters. In *State of Deep-Sea Coral and Sponge Ecosystems of the United States*. Ed. by T. F. Hourigan, P. J. Etnoyer and S. D. Cairns. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD.
- Ross, R. E., and Howell, K. L. 2012. Use of predictive habitat modelling to assess the distribution and extent of the current protection of 'listed' deep-sea habitats. *Diversity and Distributions*, 19: 433–413.
- Rowden, A. A., Stephenson, F., Clark, M. R., Anderson, O. F., Guinotte, J. M., Baird, S. J., Roux, M.-J., et al. 2019. Examining the utility of a decision-support tool to develop spatial management options for the protection of vulnerable marine ecosystems on the high seas around New Zealand. *Ocean and Coastal Management*, 170: 1–6.
- Saucède, T., Eléaume, M., Jossart, Q., Moreau, C., Downey, R., Bax, N., Sands, C., Mercado, B., Gallut, C. and Vignes-Lebbe, R., 2021. Taxonomy 2.0: computer-aided identification tools to assist Antarctic biologists in the field and in the laboratory. *Antarctic Science*, 33(1), pp.39-51.
- Schejter, L., Rimondino, C., Chiesa, I., Di'az de Astarloa, J. M., Doti, B., El'as, R., Escolar, M., et al. 2016. Namuncura´ Marine Protected Area: an oceanic hot spot of benthic biodiversity at Burdwood Bank, Argentina. *Polar Biology*, 39: 2373–2386.
- Schejter, L., Genzano, G., Gaitán, E., Perez, C. D., and Bremec, C. S. 2020. Benthic communities in the Southwest Atlantic Ocean: Conservation value of animal forests at the Burdwood Bank slope. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 30(3), 426-439.
- Sharp, B. R. 2010. Revised Impact Assessment Framework to Estimate the Cumulative Footprint and Impact on VME Taxa of New Zealand Bottom Longline Fisheries in the Ross Sea Region. WG-SAM-10/20. CCAMLR. 22 p. <https://www.ccamlr.org/en/wgsam-10/20>.
- Sharp, B. R., Parker, S. J., and Smith, N. 2009. An impact assessment framework for bottom fishing methods in the CAMLR Convention area. *CCAMLR Science*, 16: 195–210.
- Smith, P., Arneth, A., Barnes, D.K.A., Ichii, K., Marquet, P.A., Popp, A., et al. 2022. How do we best synergize climate mitigation actions to co-benefit biodiversity? *Global Change Biology*. doi:10.1111/gcb.16056.
- Souster, T. A., Barnes, D. K. A., and Hopkins, J. 2020. Variation in zoobenthic blue carbon in the Arctic's Barents Sea shelf sediments. *Philosophical Transactions of the Royal Society A*, 378(2181), 20190362.
- Staniczenko, P. P. A., Sivasubramaniam, P., Suttle, K. B., and Pearson, R. G. 2017. Linking macroecology and community ecology: refining predictions of species distributions using biotic interaction networks. *Ecology Letters*, 20: 693–707. doi:10.1111/ele.12770.
- Tatiàn, M., Antacli, J. C., and Sahade, R. 2005. Ascidians (Tunicata, Ascidiacea): species distribution along the Scotia arc. *Scientia Marina*, 69(S2), 205-214.
- Thrush, S. F., Hewitt, J. E., Lohrer, A. M., and Chiaroni, L. D. 2013. When small changes matter: the role of cross-scale interactions between habitat and ecological connectivity in recovery. *Ecological Applications*, 23: 226–238.

Tittensor, D. P., Baco, A. R., Brewin, P. E., Clark, M. R., Consalvey, M., Hall-Spencer, J., Rowden, A. A., et al. 2009. Predicting global habitat suitability for stony corals on seamounts. *Journal of Biogeography*, 36: 1111–1128.

Trygonis, V., Sini, M., 2012. photoQuad: a dedicated seabed image processing software, and a comparative error analysis of four photoquadrat methods. *Journal of Experimental Marine Biology and Ecology* 424-425, 99-108. doi:10.1016/j.jembe.2012.04.018

UNGA. 2007. Resolution 61/105 Sustainable fisheries, Including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and Related Instruments. UNGA A/RES/61/105. 21 pp. UNGA. 2015. Resolution 69/292 Development of an International Legally Binding Instrument under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction. UNGA A/RES/69/292. 3 pp.

Watling, L., and Auster, P. J. 2017. Seamounts on the high seas should be managed as vulnerable marine ecosystems. *Frontiers in Marine Science*, 4: 14.

Watling, L., France, S. C., Pante, E., and Simpson, A. 2011. Biology of deep-water octocorals. *Advances in Marine Biology*, 60: 42–122.  
Welsford, D. C., Ewing, G. P., Constable, A. J., Hibberd, T., and Kilpatrick, R. 2014. An Assessment of the Vulnerability of Benthic Habitats to Impact by Demersal Gears. FRDC project 2006/042. The Department of the Environment, Australian Antarctic Division and the Fisheries Research and Development Corporation. 266 pp.

Wilson, M. F. J., O’Connell, B., Brown, C., Guinan, J. C., and Grehan, A. 2007. Multiscale terrain analysis of multibeam bathymetry data for habitat mapping on the continental slope. *Marine Geodesy*, 30: 3–35.

Worm, B., Hilborn, R., Baum, J. K., Branch, T. A., Collie, J. S., Costello, C., Fogarty, M. J., et al. 2009. Rebuilding global fisheries. *Science*, 325: 578–585.

Wright, G., Gjerde, K. M., Johnson, D. E., Finkelstein, A., Ferreira, M. A., Dunn, D. C., Chaves, M. R., et al. 2019. Marine spatial planning in areas beyond national jurisdiction. *Marine Policy*, in press, doi.org/10.1016/j.marpol.2018.12.003.

Zworschke, N., Sands, C. J., Roman-Gonzalez, A., Barnes, D. K. A., Guzzi, A., Jenkins, S., Muñoz-Ramírez, C., and Scourse, J. 2022. Quantification of blue carbon pathways contributing to negative feedback on climate change following glacier retreat in West Antarctic fjords. *Global Change Biology*, 28, 8- 20. doi:10.1111/gcb.15898