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From sealing to the MPA - A history of exploitation, conservation and management of marine living resources at the South Sandwich Islands

M. Belchier [a,b,*], M.A. Collins [b], S. Gregory [a], P. Hollyman [b], M. Soeffker [c]

[a] Government of South Georgia and the South Sandwich Islands, Stanley, Falklands, FIQQ 1ZZ, UK
[b] British Antarctic Survey, NERC, High Cross, Madingley Road, Cambridge, CB3 0ET, UK
[c] Centre for Environment, Fisheries & Aquaculture Science, Pakefield Rd, Lowestoft, NR33 0HT, UK

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ABSTRACT

The exploitation of marine resources of the South Sandwich Islands (SSI) began with the hunting of fur seals for their pelts in the early decades of the 19th Century. Pelagic whaling in the region started a century later with catches recorded until the mid-1970s. Blue and fin whales dominated the catches accounting for 80% of the total. Trawl fisheries for demersal finfish and krill (*Euphausia superba*) were established around many sub-Antarctic islands in the late 1960s and through the 1970s, but they did not become established at the South Sandwich Islands despite fisheries research expeditions from several nations visiting the region during this period. The first licensed demersal longline fishery for toothfish (*Dissostichus* spp.) was initiated by a UK flagged vessel in 2005 following earlier expeditions by Chilean and Bulgarian fishing vessels. The fishery for toothfish is now conducted by a maximum of two vessels and represents the only fishing carried out in the SSI region with total annual catches of around 40 t per annum, with a fishing footprint restricted to less than 4% of the SSI Maritime Zone (MZ). This MZ extends 200 nm from the island chain and forms the eastern half of the 1.24 million km^2 MZ of the UK Overseas Territory of South Georgia & the South Sandwich Islands (SGSSI) which was established in 1993. The MZ around the SSI lies within the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) management Subarea 48.4. Fishing within the MZ is licensed by the Government of South Georgia & the South Sandwich Islands (GSGSSI) who, under domestic legislation, are required to adopt all fisheries management regulations that have been agreed for the region each year by CCAMLR. In addition, a suite of additional management measures are enforced. In 2012, GSGSSI established a sustainable use Marine Protected Area (MPA) within the SGSSI MZ to conserve the marine biodiversity of the region. Enhancements were introduced in 2013 and 2019 extending No-Take Zones (NTZs), where all fishing is prohibited, across 261,000 km^2 of the MZ around the SSI including the deepest regions of the Southern Ocean, the South Sandwich Trench. The SSI marine ecosystem has been relatively poorly studied but has recently been a focus of two dedicated UK research cruises providing a considerable new amount of information to assist with the management of this remote marine region.

1. Introduction

1.1. Background

The South Sandwich Islands (SSI) are a remote chain of 11 volcanic islands located in the southwest Atlantic sector of the Southern Ocean (Leat et al., 2013, 2016). They form an island arc running from north to south, extending from 56°18'–59°27'S and 26°23'–28°08'W, between 560 and 800 km southeast of the island of South Georgia (Fig. 1). The archipelago forms the eastern boundary of the Scotia Sea and lies to the north-east of the Weddell Sea which, as part of the Weddell Sea Gyre, drives sea ice out into the Scotia Sea, where it is pushed east by winds and the Antarctic Circumpolar Current (Orsi et al., 1993; Thorpe and Murphy, this issue). The South Sandwich Islands are located in the area of the most northerly extent of Antarctic sea ice (Renner et al., 2009). The archipelago lies to the south of the oceanic Antarctic Polar Front and in contrast to South Georgia also lies south of the Southern Antarctic Circumpolar Front (SACCF) and the Southern ACC Boundary Front (Fig. 1) in the biological transition region between the sub-Antarctic and maritime Antarctic (Thorpe and Murphy, this issue).

Captain James Cook discovered the islands south of Candlemas (Fig. 1) on the 30th January 1775 whilst on HMS *Resolution* (Headland,

* Corresponding author. Government of South Georgia and the South Sandwich Islands, Stanley, Falklands, FIQQ 1ZZ, UK.
E-mail address: markb@bas.ac.uk (M. Belchier).

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1984). The three northern islands of the chain (Zavodovski, Visokoi and Leskov) collectively known as the Traversey Islands (formally Traverse), were discovered by the Russian explorer Bellingshausen on the *Vostok* in December 1819 (Kemp and Nelson, 1931).

The South Sandwich Islands and the waters within 200 nautical miles (nm) form the eastern half of the UK Overseas Territory of South Georgia & the South Sandwich Islands (Fig. 1) and its Maritime Zone (MZ) which in total extends to over 1.24 million km^2. The Territory was established (by Letters Patent) in 1908 as a dependency of the Falkland Islands (Headland, 1984), but became a separate Territory by Order in Council in 1985 (South Georgia and South Sandwich Islands Order,1985). However, it was not until 1993 that the South Georgia & the South Sandwich Islands Maritime Zone (MZ) was created by proclamation (GSGSSI, 1993). The Maritime Zone, which at the SSI extends 200 nm from the baseline of the islands' mean high water, lies within the area included under the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), an international conservation and management treaty that came into force in 1982. The UK, and 26 other members, are signatories of CCAMLR and are therefore legally bound to act in accordance with all Conservation Measures agreed by the Commission (Constable et al., 2000). The objective of the Convention, as defined in its Article II, is the conservation of Antarctic marine living resources, including their rational use. The convention includes fish and shellfish species but does not extend to seals and whales, which are covered by separate conventions (the Convention for the Conservation of Antarctic Seals (CCAS) and International Whaling Commission (IWC), respectively). CCAMLR regulates fishing and conservation activities throughout the region, which approximates roughly to the area of ocean located poleward of the Antarctic Polar Front, through the legally binding Conservation Measures (CMs) (CCAMLR, 2020c). These measures are agreed through consensus by the CAMLR Commission at their annual meeting at the CCAMLR Secretariat headquarters in Hobart, Tasmania. The South Georgia & South Sandwich Islands Maritime Zone occupies approximately half of CCAMLR (FAO) Subarea 48.4 (South Sandwich Islands) but also extends into subareas 48.3 (South Georgia) and 48.2 (South Orkney Islands) (Fig. 1).

The Government of South Georgia & the South Sandwich Islands (GSGSSI) are not separate signatories to the CAMLR Convention but its interests are represented by the delegation of the UK. All CCAMLR Conservation Measures relating to the conservation and management of marine resources within the area of the SGSSI Maritime Zone are binding. However, through the application of domestic legislation, GSGSSI regulates fishing activities and adopts measures in addition to CCAMLR CMs that result in a management regime that is more robust and precautionary than is agreed through CCAMLR. The power to make laws within the Territory lies with the Crown-appointed Commissioner of SGSSI, who is the UK monarch's representative for the Territory, and is based in Stanley in the Falkland Islands. The Commissioner appoints a Director of Fisheries with whom the responsibility for the Territory's fisheries administration lies.

Since the introduction of fisheries legislation for the Territory in 1993, GSGSSI has regulated fishing within its Maritime Zone through a licensing process that has evolved substantially over time. Fisheries are currently regulated through the Fisheries (Conservation and Management) Ordinance 2000 (as amended) (GSGSSI, 2000), and the Fisheries (Transhipment and Export) Regulations 1990 (as amended) (GSGSSI, 1990). The designation of Marine Protected Areas (MPAs) and the regulation and permitting of all activity within the SGSSI marine environment, aside from fishing, is regulated through the Wildlife and Protected Areas Ordinance (2011) (as amended) (GSGSSI, 2011).

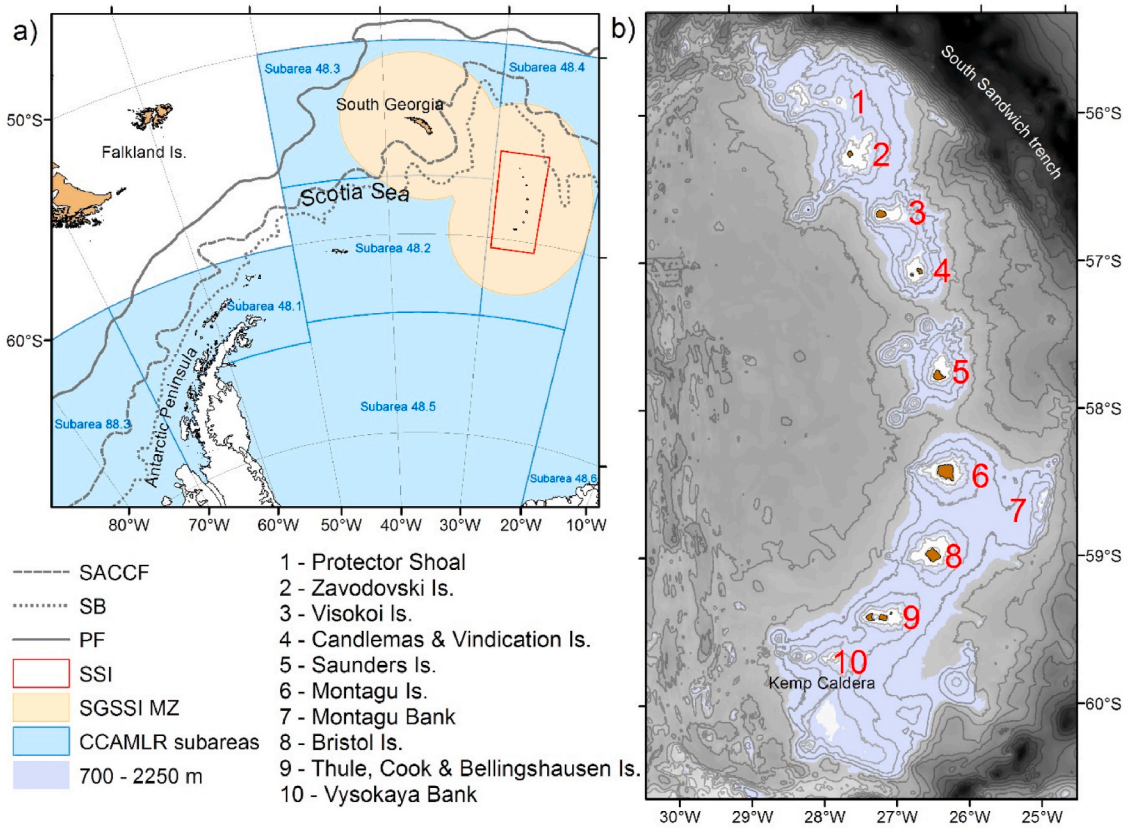

Fig. 1. a). Location of the South Sandwich Islands (red box) in the context of the wider South Atlantic. Major oceanic fronts are displayed in solid (PF – Polar Front), dashed (SACCF - Southern Antarctic Circumpolar Front) and dotted (SB - Southern ACC Boundary) lines. CCAMLR Sub areas are shown with blue borders b) detailed map of the SSI, showing islands and submarine banks. Contour lines are displayed at 500 m intervals to a depth of 8000 m in the South Sandwich Trench. Reproduced and modified from Hollyman et al., (this issue) with permission from the authors.

Due to their remoteness, extensive sea ice cover in winter and lack of any significant area of continental shelf (Leat et al., 2016), the South Sandwich Islands have not experienced the same level of exploration and exploitation of marine resources as observed at other Antarctic and sub-Antarctic islands over the last two centuries. However, despite the comparatively low levels of resource exploitation at the SSI, the same phases of exploitation occurred as those seen elsewhere. In common with South Georgia and Kerguelen, sealing expeditions arrived in the early 1800s followed by whaling in the early 1900s and then unregulated finfish fisheries from the 1970s. Today the only fishing permitted at the South Sandwich Islands is a small, highly regulated fishery for toothfish whose primary focus is the collection of data to improve the scientific understanding of the regional toothfish stocks (Söffker et al., this issue).

2. Ecological investigations of the marine environment of the South Sandwich Islands

In comparison to South Georgia, the marine environment surrounding the SSI is comparatively poorly studied with only infrequent ecological research surveys visiting the islands and their surrounding waters. This is likely a result of their remoteness but also a consequence of the limited interest in commercial fishing in the region in the 1970s and 1980s, when there was considerable fisheries research around South Georgia.

Oceanographic investigations in the region were carried out in 1926 from the German research vessel *Meteor* as part of the German Atlantic Expedition during which the South Sandwich Trench was discovered including the deepest part of the south Atlantic (north of 60°), Meteor Deep (8265 ± 13 m) (Bongiovanni et al., 2021). The first dedicated ecological research voyage to the islands was made on *Discovery II* as part of the Discovery expeditions in 1931 (Kemp and Nelson, 1931) which had a focus on whales and their associated marine ecosystem. The next major scientific expedition in 1956 on board HMS *Protector* had a greater focus on the islands themselves (Baker et al., 1964). Between November–December 1971 the Soviet research vessel, R.V. *Akademik Kurchatov* conducted benthic research in the South Atlantic sampling the hadal zone of the South Sandwich Trench discovering a rich and diverse fauna (Malyutina, 2004).

Post-1971, several scientific expeditions have surveyed all or parts of the archipelago but with a focus mainly on the islands' biodiversity rather than the marine environment. These include the HMS *Endurance*/ RRS *James Clark Ross* expedition in 1997 (Convey et al., 1999) with a focus on geological and terrestrial biological studies. Limited benthic sampling around Southern Thule was undertaken as part of the JR144 (BIOPEARL) cruise with RRS *James Clark Ross* from February–April 2006 (Griffiths et al., 2008) with a focus on the biodiversity of benthic invertebrate fauna. Surveys of the islands from the charter yachts SY *Damien II* (Convey et al., 1999) and SY *Golden Fleece* (Freer et al., 2015; Lynch et al., 2016), took place in 1997 and 1997/2011 respectively. A further yacht based, multidisciplinary survey took place in 2019/20 onboard the SY *Pelagic Australis* which focused on penguin ecology including tracking, UAV surveys, and volcanology (Dickens et al., 2021; Liu et al., 2021).

Most of the recent major oceanographic expeditions in the SSI region have focused on the region's benthic ecology and in particular its chemosynthetic and hydrothermal vent communities (Rogers et al., 2012) as part of a larger consortium project *CHESSO* (Chemosynthetic Ecosystems of the Southern Ocean). Three further research surveys (RRS *James Clark Ross* 224 and RRS *James Cook* 042 and 055) visited the SSI in 2009, 2010 and 2011 deploying ROVs and a range of benthic sampling gears to provide information on these unexplored and untouched chemosynthetic ecosystems (Linse et al., 2019). Information obtained during these cruises formed the basis for the spatial closure of the Kemp Caldera as part of the revisions to the MPA in 2013. The German research vessel, *Polarstern,* has also carried out several multi-disciplinary research cruises in the SSI region including PS119 in 2019 which investigated the macro-benthos of the hydrothermal vent systems of the SSI using the ROV *Marum Quest* (Bohrmann, 2019). Other ecological investigations using the *Polarstern* have included research in 2013 when the vessel undertook extensive krill research (Meyer and Auerswald, 2014) whilst in 2002 it conducted research as part of the LAMPOS expedition studying the ecology, biodiversity, biogeography and evolution of fauna across the Scotia Sea (Arntz and Brey, 2003).

In 2019, an expedition (Five Deeps) on board DSSV *Pressure Drop* deployed a manned submersible into the depths of the South Sandwich Trench for the first time (Jamieson et al., this issue). Extensive bathymetric mapping of the trench was carried out using side-scan sonar (Bongiovanni et al., 2021), providing new data on the deepest point of the Southern Ocean (south of 60°) which was found to reach a depth 7432 ± 13 m at the southern end of the South Sandwich Trench.

Two UK led, multi-disciplinary research cruises, funded through the UK government's Blue Belt Programme were carried out from the RRS *Discovery* in the SSI region in 2018/19 to obtain environmental and ecological data to assist with the management of the MPA. During the first of these surveys (DY98) a series of acoustic transects were run to estimate the biomass of krill at the SSI for the first time since the CCAMLR synoptic survey in 2000 carried out by the Russian vessel *Atlantida* (Krafft et al., 2021).

The second RRS *Discovery* (DY99) survey in 2019 focused on the collection of data on the ecology and diversity of the seafloor invertebrate communities at the South Sandwich Islands (Downie et al., 2021; Hogg et al., 2021). Deep-water camera and scientific trawl deployments were made to sample benthos around many of the islands. These data were used to assess the impacts of longline fishing on vulnerable marine ecosystems (VME) at the South Sandwich Islands which were an area highlighted as a priority for research at the 2018 MPA review. The results from this study have indicated that the impact of the demersal longline fishery is limited and the MPA's fishery depth restrictions are an effective means of reducing interactions between fishing operations and vulnerable marine organisms (Downie et al., 2021; Hogg et al., 2021).

Fish and fisheries research at the SSI has been even more limited. In addition to West German research in 1975/76 (see section 3.2.1) the Argentine research vessel ARA *Islas Orcadas* conducted limited research bottom trawling in May 1975 with a 'Blake trawl' at 15–70 m depth in a region between Candlemas and Vindication Islands (Dewitt et al., 1976). The results of Soviet bottom trawl research fishing in the SSI region were reported by (Permitin, 1977). Spain also undertook demersal finfish research at the SSI in late December 1986 (Balguerias, 1989) when the stern trawler *Pescapuerto Cuatro* conducted eight hauls between 190 and 250 m depth using a commercial size bottom trawl net. The Scotia Sea icefish, *Chaenocephalus aceratus*, dominated catches that were made mainly around the islands from Saunders southwards apart from two trawls at Zavodovski. Nearly two decades later in June 2004 the R/V *Nathaniel B Palmer* 'ICEFISH' expedition surveyed the region using a suite of net sampling gears as part of an expedition to survey the ecology of fishes across the wider north Scotia Ridge and Bouvet regions (Detrich et al., 2012; Lockhart and Jones, 2008).

Krill distributions were studied by CCAMLR members during a multinational synoptic survey of krill across the Scotia Sea in order to provide an estimate of regional krill biomass in 2000 (Trathan et al., 2001). Data derived from this research formed the basis of the current CCAMLR krill management in the region and was repeated in 2019/20 (Krafft et al., 2021).

3. History of exploitation

3.1. Sealing and whaling

There is evidence that the SSI may have been visited by sealers prior to their official discovery in 1775, with sealing expeditions also possibly visiting the islands from 1816 to 1818 (Headland, 1984). There are

further detailed reports of three sealing expeditions to the region between 1823 and 1830 although none reported any animals being taken (Holdgate and Baker, 1979). Sporadic expeditions continued until the end of the 19th Century and some of these were successful, reportedly taking as many as 4000 seal pelts in a single season (1876/77) although subsequent expeditions were less successful with no pelts reported at all in some seasons. While overall sealing around the SSI was considerably less intense than at South Georgia during this period, the northern islands were likely to have experienced much more intense exploitation than those in the south. Over 6000 fur seal (*Artocephalus gazella*) pelts were recorded as taken from the SSI between 1875 and 1892, and there were no subsequent reports of fur seal sightings on the islands until 1957 (Headland, 1984) suggesting that sealing had a major impact on their local population abundance. A survey in 1908 of the SSI by the vessel *Undine* landed on seven of the islands (Kemp and Nelson, 1931) but reported no occurrence of fur seals. It has been suggested that unreported sealing activities may have led to a major decline in their numbers (Holdgate and Baker, 1979).

The numbers of fur seals breeding at the SSI today is small compared to South Georgia and limited to the islands north of Montagu Island (Hart and Convey, 2018). Numbers are thought to have recovered to some extent in line with the observations at South Georgia and are thought to be stable or increasing, although reliable data have been hard to obtain given the inaccessibility of breeding beaches and the harsh

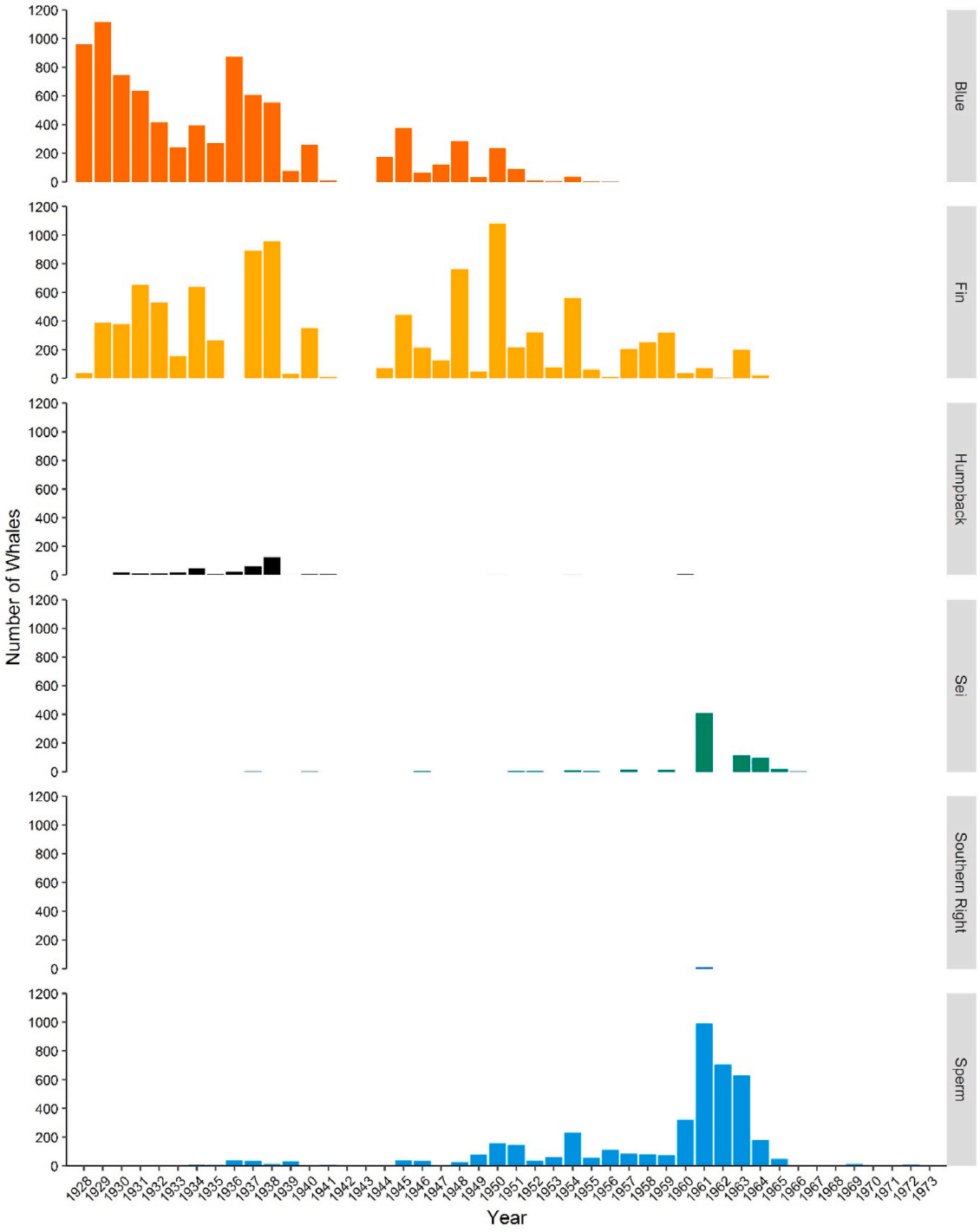

Fig. 2. Annual reported whale catches in the SSI region (see text for spatial coverage) between 1928 and 1973.

conditions. Fur seal pup counts were conducted on breeding beaches throughout the archipelago in 2011 (Hart and Black, 2011) but there has been no systematic census of the fur seal population since.

Carl Anton Larson, who established the first whaling station at Grytviken, South Georgia in 1904 surveyed the SSI in the vessel *Undine* in that year, landing on seven of the islands (Kemp and Nelson, 1931). In 1911 the first dedicated whaling expedition to the region was carried out by two Norwegian vessels (*Thulla* and *Havfruen*) under Captain Ole Jorgensen but no further whaling activity was recorded until Captain H. Hansen visited the islands in 1927 on the whale catcher *Busen VII* and reported that whales were plentiful (Kemp and Nelson, 1931). The following year the whaling factory ship *Anglo-Norse* worked around the islands following which regular pelagic whaling expeditions to the region took place.

International Whaling Commission (IWC) catch records for the region covering the area of the Scotia Sea between 55° and 62° S and between 22° and 30°W (encompassing the majority of the eastern half of the SGSSI Maritime Zone) show that considerable numbers of whales were killed in the vicinity of the SSI between the late 1920s and the late-1970s (Allison, 2020). Nearly 22,600 whales of six species were recorded as being killed in the SSI region between 1928 and 1978. The majority were killed by Norwegian, British and Soviet vessels but small numbers of whales were also taken by German, Dutch, Japanese and United States of America operations. A total of 78 whaling expeditions visited the region over this period (Allison, 2020). Blue and fin whales dominated the catches (Fig. 2) accounting for 80% of the total whale catch by number with both species declining significantly over the first three decades. Low numbers of humpback whales were also taken in the region in the 1930s. By the 1960s sperm whales were the most frequently caught species along with small numbers of sei whales and ten southern right whales caught in the region in 1961. Whale catches were recorded across the SSI region but the highest numbers were reported from the south of the SSI region between 59° and 61° south. The last recorded whaling activity at the SSI was in 1978 by the USSR.

3.2. Finfish resources

3.2.1. First exploitation

By the late 1960s, following the decrease of whale numbers in the Southern Ocean, fleets of Soviet and eastern European trawlers started to exploit the demersal finfish stocks of the continental shelf regions of the south Atlantic and Southern Ocean (Kock, 1991). Bottom trawl fisheries for the nototheniids (rock cods), most notably the marbled rock cod, *Notothenia rossii*, started at South Georgia in 1969, although there is evidence of earlier fisheries research expeditions in the region (Agnew, 1995; Hollyman et al., 2021). Exploitation of fish stocks was unregulated, leading to a rapid collapse of marbled rock cod stocks by the early 1970s at which time fishing switched to other species, most notably the icefishes (channichthyids) which experienced a similarly rapid (<decade) decline (Kock, 1991, 1992).

The West German research vessel *Walther Herwig* and the chartered trawler *Weser* surveyed the fish and krill resources of the region in the austral summer of 1975/76 (Kock, 1978) and found that the northern SSI had a similar, although less diverse, ichthyofauna to that found at South Georgia (Targett, 1981) including many of the species exploited elsewhere in the Southern Ocean (Kock, 1992). The survey found primarily icefish species Scotia Sea icefish (*Chaenocephalus aceratus*), mackerel icefish (*Champsocephalus gunnari*) and South Georgia icefish (*Pseudochaenichthys georgianus*. The first commercial catches were reported from the South Sandwich Islands in 1981, by the Polish distant water fishing fleet (CCAMLR, 1984), which caught several hundred tonnes of rock cod (*Gobionotothen gibberifrons*) and the same icefish species as during the previous survey (*C. aceratus*, *C. gunnari*, and *P. georgianus* (CCAMLR, 1984)). However, catches were low compared to those at South Georgia and while similar species of commercial interest were found at the SSI, fishing did not expand from South Georgia at the time, possibly due to the steep, volcanic slopes and resulting limited continental shelf area or similar habitats. Although demersal trawl research surveys were carried out infrequently in the region since the 1980s, a regular commercial bottom trawl fishery never became established in the region.

3.2.2. South Sandwich Islands toothfish fisheries

By the late 1980s, a new fishery had started to develop at South Georgia for Patagonian toothfish, *Dissostichus eleginoides*, a slow growing, long-lived notothenid fish with a circumpolar distribution that, when mature, inhabits the deeper waters of the continental shelf and shelf break of the sub-Antarctic region (Collins et al., 2010). The species was caught as bycatch in the trawl fisheries operating on the South Georgia shelf in the 1970s and early 1980s, but in 1988, a demersal longline fishery was initiated at South Georgia by Soviet vessels operating at greater depth on the shelf break. This precipitated an increased interest in the use of demersal longlines and the development of fisheries for toothfish across the Southern Ocean.

Following the development of the South Georgia fishery, there was interest in investigating the potential for commercial toothfish fisheries in other areas and following interest from some members, CCAMLR introduced the first binding Conservation Measure for SSI toothfish in November 1992 (CM 44/XI) setting a catch limit of 240 tonnes for an exploratory toothfish expedition by Chile. In the same month, the first reported catches of toothfish (39 tonnes) were taken at the SSI by a Bulgarian vessel operating in the northern area around Protector Shoal and Zavodovski and Visokoi Islands, not in accordance with the agreed CM but which were reported to CCAMLR (CCAMLR, 1993). Further exploratory fishing was carried out later that summer (Feb. 1993) by the Chilean vessel, *Friosur V* (CCAMLR, 1993) that fished in the region for a week under CM 44/XI.

Results obtained from the Bulgarian fishing operation initially indicated catch rates of toothfish equivalent to those achieved by the same vessel at South Georgia, however, catch rates reported by the Chilean vessel were very low compared to those obtained at the time from South Georgia from the regions fished by both Chile and Bulgaria. CCAMLR concluded that the low catches of toothfish at SSI would not support a commercial fishery for this species (CCAMLR, 1993), and on the basis of these results, CCAMLR set a precautionary catch limit of 28 tonnes for Patagonian toothfish at the SSI (CCAMLR Subarea 48.4) with no further fishing activity expected. There are no records of illegal, unregulated and unreported (IUU) fishing at the South Sandwich Islands within the CCAMLR database, although surveillance coverage in the region at this time would have been exceedingly limited and the presence of unlicensed vessels cannot be ruled out given that IUU was known to be widespread in the Convention area (Miller et al., 2010).

There was renewed interest in fishing for toothfish at the SSI in 2005 when a single UK-flagged vessel initiated a mark-recapture programme in the waters lying north of 60° S. This UK initiative was endorsed by CCAMLR as the tagging study aimed to obtain data on the distribution, density, movement and population dynamics of the regional Patagonian and Antarctic toothfish (*Dissostichus mawsoni*) stocks to inform the development of stock management (Roberts, 2012). The research fishery included a requirement for high levels of fish tagging (15 fish tagged per tonne). This proved to be highly successful in providing information which has significantly improved the understanding of the ecology of both toothfish species (Söffker et al., this issue) fished at the SSI. There now exists a far greater understanding of the movement of Patagonian toothfish between the SSI and South Georgia and reliable estimates of regional stock size for both species.

In 2008, CCAMLR agreed that the fishery should be spatially divided into northern and southern areas with directed fishing in each area limited to Patagonian and Antarctic toothfish respectively. The success of the tagging programme led to the rapid development of an integrated stock assessment for Patagonian toothfish which CCAMLR endorsed for the Patagonian toothfish stock in 2009, using information derived from

the tagging programme as the key input parameters. In 2013, with more data and information available, CCAMLR adapted the management approach in the subarea by setting separate subarea-wide catch limits by species, with each stock assessed for the entire region and removing the management split between the northern and southern islands of the archipelago (CCAMLR, 2020a). The integrated stock assessment is implemented in CASAL (C++ Algorithmic Stock Assessment Laboratory) software (Bull et al., 2012) and uses a suite of input data relating to stock productivity but depends largely on tagging data. If the catch limit for *D. eleginoides* is reached before the close of the fishery then the region north of 58°S is closed whilst if *D. mawsoni* limit is reached the area south of latitude 57°20'S will close to reflect the difference in spatial distribution between the two species (Hollyman et al., this issue).

The toothfish fisheries at the SSI have had 100% observer coverage under the CCAMLR Scheme of International Scientific Observation (SISO) from the outset. SISO observers record information on the fishing gear configuration (including measures to reduce incidental mortality of seabirds and marine mammals), fishing operations (including catch composition), biological measurements of target and by-catch species, details of fish tagging and tag-recaptures and vessel sightings. Observer derived data is one of the most important sources of scientific information that is essential for assessing the impact of fishing on the ecosystem, including the status of target populations, as well as those of related and dependent species.

The extensive collection of data from these fisheries has also greatly improved the understanding of the distribution and ecology of non-target species (Roberts, 2012; Roberts et al., 2011). This has included the provision of data on the macrourids, (Hollyman et al., this issue), skates (Goodall-Copestake et al., 2018) and muraenolepids (Fitzcharles et al., 2021) as well as providing information on impacts of the fishery on benthic invertebrates. In addition the research provided new information on the strong connectivity of the SSI population of Patagonian toothfish to that found at South Georgia, and on the relationship between the SSI Antarctic toothfish around the southern islands and the wider stock found in the south Atlantic sector (Area 48) (Söffker et al., this issue).

3.2.3. CCAMLR decision rules and domestic legislation

The catch limits set by GSGSSI for Patagonian toothfish at the SSI are lower and more precautionary than those agreed at CCAMLR. CCAMLR catch limits are based on CCAMLR Decision Rules, a set of rules that ensure that the long-term maintenance of a spawning biomass is safeguarded. The Decision Rules are used to determine catch limits as follows:

1. There is 10% or lower probability that spawning biomass projections drop below 20% of the pre-fishing median biomass over 35 years, *and*
2. For toothfish species the spawning biomass is forecast to be at or above 50% of the pre-fishing median after a 35-year period of fishing.

The smallest catch that ensures that both of these criteria is met is selected.

At SSI however, an additional long term management objective of setting a catch that will maintain the local stock at or above 55% of the estimated pre-fishing biomass after 35 years has been adopted by GSGSSI rather than the 50% agreed by CCAMLR (GSGSSI, 2018b). This provides greater flexibility for introducing local management measures and provides a greater 'buffer' against uncertainty in estimates of fish recruitment or depredation in the stock assessment model and gives rise to catch limits that are approximately 20% lower than those set by CCAMLR. The SSI toothfish fishery is regarded as the exemplar of how, through robust data collection, a toothfish fishery can transition rapidly from limited data on which to base management advice, to one that is subject to robust integrated stock assessments that use a wide range of fishery-derived data to set precautionary catch limits.

Catch limits for the local stock of Antarctic toothfish at the SSI, which is a small part of a much wider stock, are based on the application of a highly conservative exploitation rate (3.8%) (GSGSSI, 2018b) to the biomass estimated from the extensive mark-recapture (tagging) research. It is considered a precautionary approach for managing this small range-edge population that is part of a much larger stock that putatively extends into the southeast Atlantic sector of the Southern Ocean and the seamounts and continental slope of the Antarctic continent (Soeffker et al. this issue). The combined catch of toothfish at the SSI has never exceeded 100 tonnes (98 tonnes (total for both species) was caught in 2007/08 (Söffker et al., this issue)) and these remain the only fisheries permitted by GSGSSI at the South Sandwich Islands. The fishery is currently restricted by CCAMLR (CM 41–03; CCAMLR, 2020c) to operating within clearly defined boxes lying to the north of 60° (Fig. 3).

In addition to those related to fishing activities, further CCAMLR conservation measures (CMs) apply to the SSI toothfish fisheries that aim to reduce or eliminate the wider ecosystem impacts of the fishery, including move-on rules specifically aimed at limiting the impact of macrourid and skate bycatch whereby vessels must move 5 nm away from an area if the catch of these species is above a prescribed threshold on any longlines set (CM 41–03, CCAMLR, 2020c). The fishery is also subject to CM 25–02 (CCAMLR, 2020c) to minimize incidental mortality of seabirds. All vessels must adhere to a suite of measures including the use of streamer lines and other bird exclusion devices to minimize interaction of fishing gear with birds during setting and hauling operations (Collins et al., 2021). Vessels must only use longlines with specified weighting regimes to ensure fast sink rates, whilst the discarding of fish offal during longline setting is prohibited. The incidence (and risk) of bird bycatch within the SSI toothfish fishery is exceptionally low with only one bird mortality recorded in the fishery since it began in 2005. A combination of very high compliance with bird mitigation measures (Collins et al., 2021) and a comparatively low abundance of vulnerable flying seabirds in the region when the fishery operate (Handley et al., 2020) is likely to have contributed to this outcome.

Vessels licensed by GSGSSI to fish at the SSI must adhere to a range of domestic fishery licence conditions in addition to the CMs required by the CCAMLR (GSGSSI, 2018b, c). This includes a requirement that all vessels operating there must have ice strengthening, equivalent to Den Norsk Ice Class 1 to reduce the risk of ice damage to vessels. Tamper proof electronic monitoring (EM) systems for independent observation of hauling and setting operations is mandatory for all fishing operations. All licensed vessels must also undertake additional data collection and tagging (research longline sets) in predefined areas prior to commencing any commercial fishing to support GSGSSI research within the framework of its MPA. This enables a continuation of the robust time series for fish density/catch per unit effort (CPUE) data and ensures an appropriate distribution of fish tagging effort. Vessels must abide by all regulations in force within the MPA and are prohibited from operating within Benthic Closed Areas (BCAs) and No-Take Zones (NTZs) (see section 3.1).

A three-year fishery research programme developed by the UK was undertaken to collect data on the distribution, abundance and connectivity of Antarctic toothfish within the region of the Maritime Zone south of 60° and was permitted by GSGSSI between 2017 and 2019 (Söffker et al., 2021). The research, which spanned parts of CCAMLR Subareas 48.2 and 48.4, was carried out under a CCAMLR research exemption through CM 24–01 (CCAMLR, 2020c). Two vessels collected data from prescribed fishing locations at depths between 800 and 1900m. The results provided evidence linking *D. mawsoni* with the Antarctic continental shelf and indicated a potential *D. mawsoni* spawning region in Subarea 48.2. The movements of recaptured tagged fish indicate potential connections with the Lazarev Sea (Subarea 48.6) as well as the southern South Sandwich Islands. This research also provided new information on target species and bycatch from previously un-fished areas

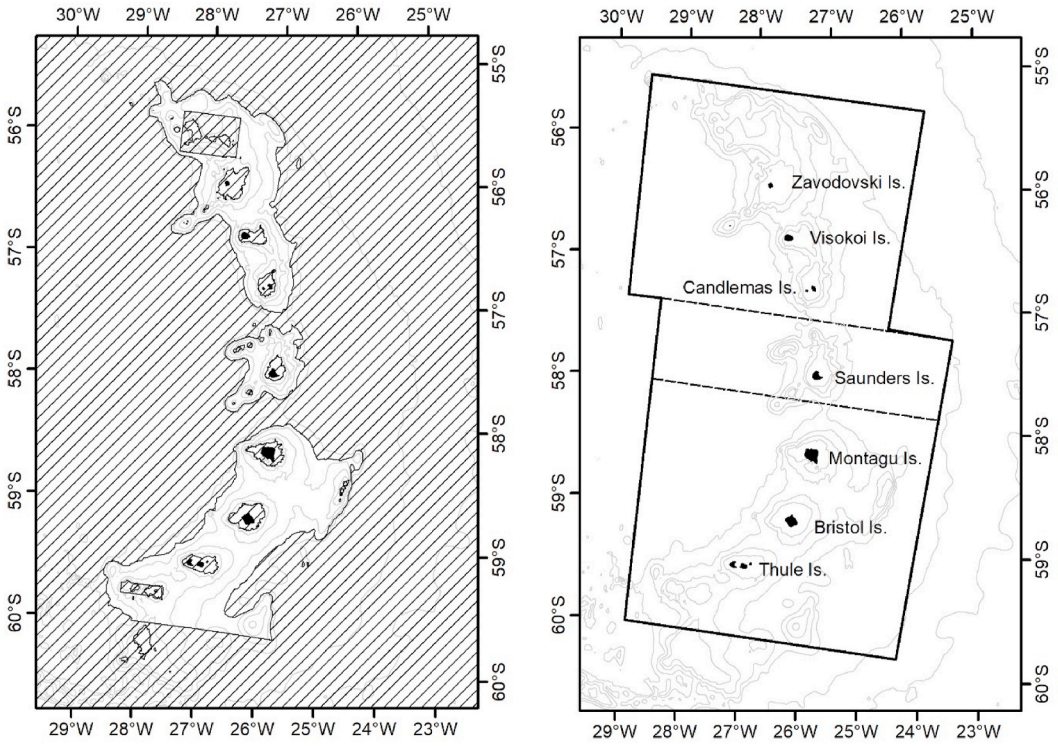

Fig. 3. GSGSSI regulations (left) prohibit fishing at depths shallower than 700 m or deeper than 2250 m greatly reducing the area of seabed open to fishing. Longline fishing is permitted only in the non-hatched region. CCAMLR's spatial limits on the SSI toothfish fishery (CM 41–03) (right).

which was used to inform the first SGSSI MPA review (see section below). In 2019 all of the area lying south of 60° within the SGSSI MZ was declared as a No-Take Zone.

3.3. SSI krill resources

The fishery for Antarctic krill (*Euphausia superba)* developed in the Indian Ocean sector of the Southern Ocean in the early 1970s but over the subsequent decades became focused in the SW Atlantic (Area 48) and in particular in the region of the Antarctic Peninsula, South Orkneys and South Georgia (Nicol and Foster, 2016; Nicol et al., 2012). Initially pursued by predominantly Soviet and Japanese vessels, catches from the krill fishery have been dominated by Norwegian vessels over the last decade, with Chinese vessels taking an increasing percentage of the catch in the last 5 years. Annual catches are variable but have been slowly increasing, reaching over 440,000 tonnes in 2020 (CCAMLR, 2020b).

Despite the distribution of Antarctic krill extending to the South Sandwich Islands, where it sustains the large numbers of krill predators including penguins, whales and seals, a krill fishery never became established in this region. Analysis of the CCAMLR statistical bulletin (CCAMLR 2021) shows that there was some limited krill research and fishery prospecting in the early 1970s by Japan when 19 tonnes of krill was caught over 15 days fishing. A survey of krill resources at the South Sandwich Islands was also carried out by West Germany in 1975/76 as part of the fisheries research investigations from the vessels *Weser* and *Walther Herwig* although reported catches were small (Sahrage, 1978). Since the introduction of CCAMLR's fishery reporting requirements in 1982 there has been a total reported catch of 61 tonnes of krill taken at the SSI (CCAMLR Subarea 48.4) with fishing limited to just three fishing days, the last of which was a single day of research fishing by a Russian vessel in July 1992. Since the proclamation of the SGSSI MZ in 1993 there has been no commercial krill fishing at the SSI, although an allocation of the catch limit to the region (CCAMLR sub area 48.4) as part of the wider quota for the Scotia Sea (CM 51–07; CCAMLR, 2020c) remains in force (see below). One GSGSSI-licensed Norwegian vessel spent time searching for krill in the region in 2013 but no catch was taken (GSGSSI, 2013b). GSGSSI fishery and MPA regulations restrict krill fishing to the winter months (as South Georgia) when competition between a fishery and krill dependent predators is greatly reduced. However, in most years seasonal sea ice extends north of Saunders Island making vessel access to the area difficult (Trathan et al., 2014). The MPA measures (see below) also serve to restrict any krill fishing to beyond the 50 km pelagic No-Take Zones surrounding the islands. Furthermore, GSGSSI transhipment legislation requires all vessels to sail back to South Georgia for any transshipment of catch as vessels are legally bound to transship within Cumberland Bay East on the north coast of South Georgia (GSGSSI, 1990). The regulations above coupled with unpredictable supply of krill to the SSI and their remote location makes the development of a krill fishery there unlikely.

3.3.1. Management of krill fisheries

The CCAMLR Decision Rules are used as the basis for setting the annual maximum krill catch by the fishery (CCAMLR, 2020b; Hill et al., 2016), however unlike for toothfish, spawning biomass of krill must be maintained at 75% of the pre-fishing median level after a 20-year period of fishing. The krill stock within the SGSSI MZ is not considered to be a separate stock but part of a larger krill stock complex covering the South Atlantic sector of the Southern Ocean (western Antarctic Peninsula, South Shetlands and South Orkneys, Scotia Arc, South Georgia, South Sandwich Islands; (Hill et al., 2016). In 2000, the South Atlantic stock biomass was estimated at around 60.3 million tonnes by the CCAMLR Synoptic (acoustic) Survey (Trathan et al., 2001; Hill et al., 2016). On the basis of that survey estimate, a model-based catch limit was calculated at 5.6 million tonnes for Area 48 but acknowledging that a more precautionary approach would be needed for this data-poor stock, the total annual catch limit from Area 48 was limited to 620,000 tonnes. In line with CM 51–07 (CCAMLR, 2020c) the fishery cannot exceed this level (the trigger level) until there is an agreed mechanism to distribute catches in a manner designed to avoid localised ecological impacts. The

trigger level has been further subdivided such that catches in any one season may not exceed 25% of the trigger level in Subarea 48.1, 45% in Subareas 48.2 and 48.3 and 15% in Subarea 48.4 (CM 51–07). Consequently, whilst no krill fishery has operated at the SSI, a CCAMLR catch limit of 93,000 tonnes remains in force (Hill et al., 2016).

4. Conservation and management

4.1. Spatial management and the MPA

The SGSSI MPA (Trathan et al., 2014) legally came into force in 2012 (GSGSSI, 2012) covering an area of just over one million km^2 and extended over all of the SGSSI MZ lying north of 60° S (Figs. 1a & 4a). The primary objective of the MPA is to 'Conserve marine biodiversity, habitats and critical ecosystem function' (GSGSSI, 2013b), whilst still allowing the continuation of sustainable and highly regulated fisheries. The MPA built on a range of spatial and temporal management restrictions that were already established as part of the fishery licensing regulations in SGSSI waters which included a complete ban on commercial bottom trawling, seasonal fishery closures, depth restrictions on fishing and 'Reduced Impact Areas' (RIAs), where fishing was limited to conserve benthic habitats. Following the declaration of the MPA, many of the measures that were already in force for South Georgia also became mandatory at the South Sandwich Islands such as the 700 m minimum bottom fishing depth for longlines. Additionally a No-Take Zone (NTZ) extending to 3 nm from mean high water for each of the 11 islands came into force (Trathan et al., 2014).

In parallel with the initial declaration of an MPA, GSGSSI convened a scientific workshop to consider what additional protection might be appropriate within the newly created MPA. The workshop produced a series of recommendations, which formed the basis of a stakeholder consultation. Following that consultation new measures were agreed and the 2012 Order was repealed and replaced in 2013 with the South Georgia and South Sandwich Islands Marine Protected Areas Order (GSGSSI, 2013a). These enhancements to the existing protection included the addition of BCAs, where all bottom fishing is prohibited, a seasonal closure of the krill fishery (although none had ever operated at the South Sandwich Islands) and a 12 nm pelagic closed area around each of the South Sandwich Islands within which pelagic fishing is prohibited (i.e. bottom longlining is the only fishing gear permitted in this zone).

BCAs were declared at Protector Shoal, located to the north-west of the South Sandwich chain and the Kemp Seamount and Calderas located to the SW of the island chain (Figs. 1 & 4b). The latter is a region of hydrothermal vent activity around which exists a unique fauna dominated by a species of yeti crab (Rogers et al., 2012).

The MPA measures were reviewed after five years by a panel comprising GSGSSI fishery managers, scientists, representatives from environmental NGOs and both fishing and tourism industry sectors and was led by an independent chair (GSGSSI, 2018a). The panel assessed if the MPA measures were achieving their stated objectives and whether additional measures should be considered in light of new data and scientific information published since the MPA came into force in 2013. The scope of the review covered the whole of the MPA and considered the broader Maritime Zone but there was a particular focus on the SSI.

The panel concluded that the MPA was likely to be reaching its conservation and management objectives. A range of additional measures were suggested for consideration by GSGSSI to enhance the protection given to the region's marine ecosystems. The panel also noted that the SSI marine environment had been little studied compared to that of South Georgia, and a range of information gaps were identified where future research would be of benefit. However, no consensus was reached by the panel as to whether there would be significant conservation gains achieved by implementing the NGO-led proposal to close the whole area of the SSI MZ north of 60° to commercial fishing.

Responding to the outcomes and evidence arising from the review, GSGSSI announced a series of further enhancements in late 2018 that came into force through legislation in 2019 (GSGSSI, 2019). Many of these additional measures were focused on the SSI and included a significant increase in the areas contained within NTZs (Fig. 4b; Table 1). This was driven by declaring all of the MZ located south of 60° as a NTZ, a region of diverse bathymetry and seamounts, along with the extension of the NTZ to cover the majority of the largely unexplored and unique hadal environment of the SSI trench (Bongiovanni et al., 2021; Jamieson et al., this issue). Other notable enhancements to the MPA at the SSI included the extension of the pelagic closed area to 50 km from island baselines based on new information relating to the foraging behavior of chinstrap penguins found in vast colonies on the islands (Lynch et al., 2016). Although not of direct relevance to the SSI, the enhancements also included a two-month extension to the seasonal closure of the krill fishery across the MPA, further constraining the krill fishery to the winter months (May–September) when many krill predators, such as whales and seals are less abundant.

The MPA currently extends over the whole SGSSI MZ covering in excess of 1.24 million km^2 of which over 280,000 km^2 lies within NTZs where all fishing activity is prohibited. The spatial and depth restrictions of the MPA have resulted in less than 4% of the over 500,000 km^2 of seafloor being open to longline fishing. Importantly for the SSI, given the growth of underwater mining industries across the globe, additional legislation introduced in 2019 also prohibits any mineral extraction or mining within the SGSSI MZ.

A further development resulting from the MPA review has been the production of a research and monitoring plan (RMP) for the SGSSI MPA by the British Antarctic Survey (BAS) funded through the UK Government's *'Darwin Plus'* scheme for biodiversity research (GSGSSI, 2021). The SGSSI MPA RMP is a framework through which scientists and stakeholders are encouraged to collect, access and analyse data, including relevant baseline data and biodiversity indicators. Data collected and analysed under the plan can be used as a basis to evaluate the effectiveness of the MPA in relation to its conservation and management objectives, to consider whether the boundaries of the MPA continue to encompass the features associated with specific MPA objectives, and to further understanding of the ecosystems and resources that the MPA protects. It also aims to help evaluate threats to biodiversity, including from climate change, fishing and invasive species, as well as the impacts of tourism and scientific activities.

5. Conclusion

The marine environment of the SSI is considered by some to be untouched or pristine, however, the region was in fact subjected to high levels of whaling and sealing activities in the 19th and 20th Centuries. These activities resulted in localised depletions of higher predators that is likely to have significantly modified the regional food web, and it would therefore be inappropriate to consider the SSI marine ecosystem as pristine. The absence of fur seals in the region reported over many decades and the substantial reduction in whale numbers highlights that even the most remote areas on Earth were not protected from the detrimental and far-reaching consequences of these extractive activities.

In contrast to the high levels of exploitation of marine mammals, commercial trawl fisheries for demersal finfish or shellfish were never established at the South Sandwich Islands despite the systematic prospecting in the region in the 1970s. The remoteness of the region, coupled with a lack of extensive continental shelf habitats and their extremely challenging bathymetry for bottom trawling, likely prevented fisheries for rock cod or icefish developing. Similarly, the rapidly developing Southern Ocean krill fishery, with catches reaching a peak at South Georgia in the 1980s, never established at the SSI with the archipelago's remoteness, lack of shelter and safe anchorage and a less predictable supply of krill being the likely reasons. As Antarctic krill at SSI is considered to be part of the single Southern Ocean population, changes to krill biomass in the Antarctic Peninsula, South Orkney and

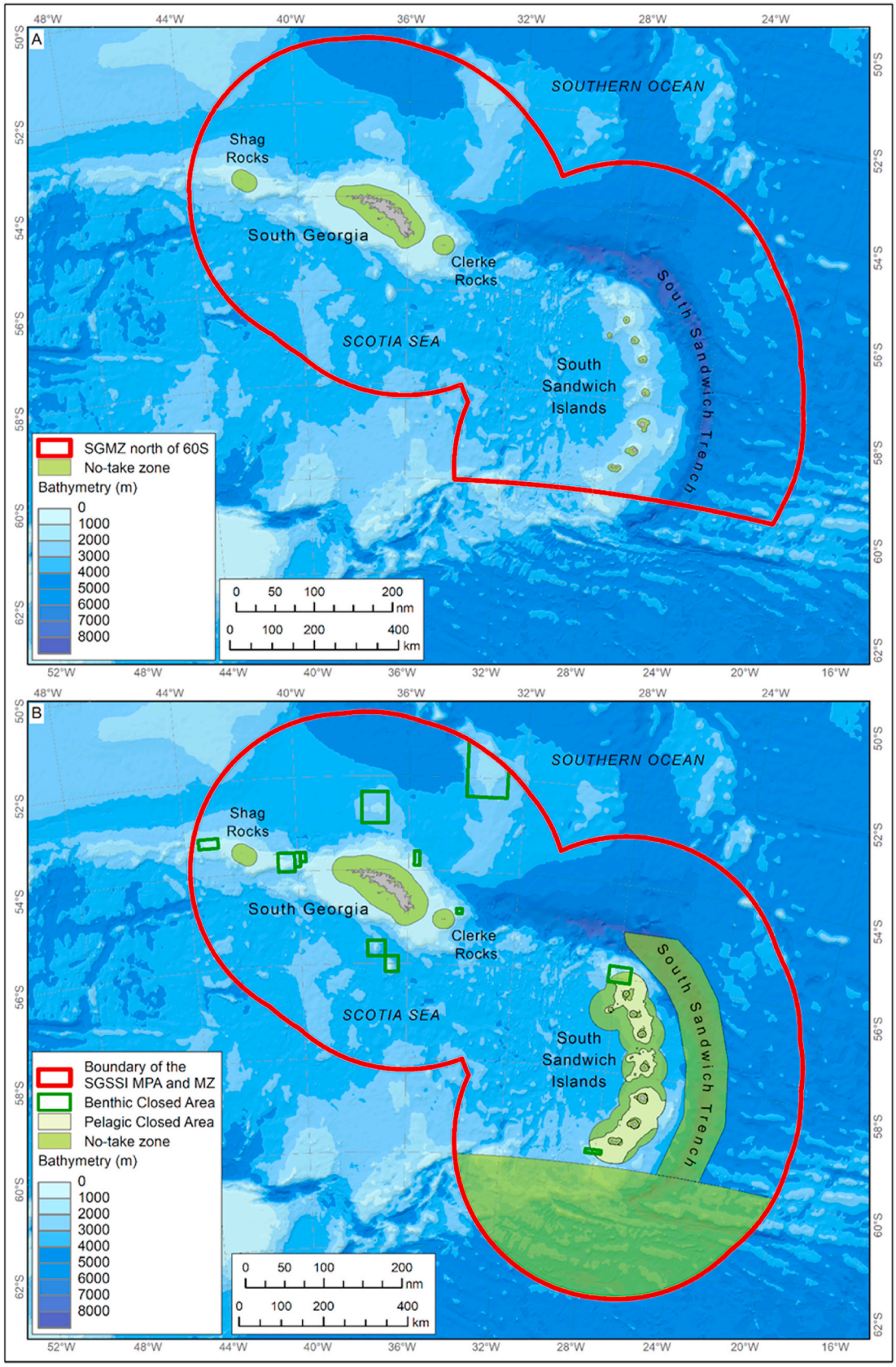

Fig. 4. Development of the SGSSI MPA measures over the last decade. MPA measures in force in 2012 (A) at the SSI include the 3 nm No-Take Zones around each island with no extension of the MPA south of 60°. Additional MPA measures that came into force in 2019 (B) include extension of NTZs to 50 km around each island, the introduction of the South Sandwich trench NTZ and prohibition of fishing in all areas south of 60°. The research fishery for toothfish is permitted within the pelagic closed area around each island and is limited to depths of 700–2250 m.

Table 1
Details of MPA spatial measures including conservation objectives currently in force specific to the South Sandwich Islands region. The table modified from the current GSGSSI MPA ordinance (GSGSSI, 2019).

Zone	Boundaries	Protected features	Conservation objectives To conserve & protect:
South Sandwich Islands No-Take Zones	Between: (1) lines 3 nautical miles from the baselines around the coasts of the South Sandwich Islands; (2) mean high water at spring tide; and (3) lines from 3 nautical miles to 26.99 nautical miles excluding those areas where water depths range from 700 – 2250 m.	The seabed, overlying water and associated organisms in areas that total 28,054 km^2.	The shallow marine environment around each of the South Sandwich Islands including: 1. the inshore foraging grounds of marine predators; 2. the spawning grounds of fish species; 3. all benthic habitats shallower than 700 m and deeper than 2250 m.
South Sandwich Trench No-Take Zone	A line (a) 26.99 nautical miles around a baseline through the midpoint of the South Sandwich Trench defined as: 55°0′0″S – 27°9′25″W 55°44′56″S – 25°32′49″W 56°19′59″S – 24°48′11″W 57°30′4″S – 24°2′24″W 58°42′25″S – 23°43′16″W 60°0′0″S – 24°23′24″W and (b) extending between 55°S and 60°S	The seabed, overlying water and associated organisms in an area of 62,900 km^2.	To conserve and protect a unique biogeographical feature which could potentially contain rare or unique habitats and biodiversity including hydrothermal communities.
No-Take Zone south of 60° South	The area lying to the south of 60° South and inside the 200 NM SGSSI Maritime Zone as measured from (1) the baselines around the coasts of the South Sandwich Islands; and (2) mean high water at spring tide.	The seabed, overlying water and associated organisms in an area of 170,479 km2	To conserve and protect unique biogeographical feature which include seamounts, deep trenches and a large area of the South Sandwich Fracture Zone and Herdman Bank - regions of high hydrothermal and tectonic activity.
South Sandwich Islands Pelagic Closed Area	Between: (1) a line 26.99 nautical miles from the baselines around the coasts of each of the South Sandwich Islands; (2) mean high water at spring tide; and (3) those areas where water depth is between 700 – 2250 m	The pelagic ecosystem around each of the South Sandwich Islands in an area of 23,755 km2.	The pelagic ecosystem and dependent predators in the area around each of the South Sandwich Islands, particularly the highly abundant chinstrap and Adelie penguins.
Protector Shoals Benthic Closed Area	55°45’ – 56°05’ S; 27°30’ – 28°20’W.	The seabed, and associated organisms in an area of 1935 km2.	The potentially sensitive (but largely unknown) benthic fauna; provides refugia for adult toothfish.
Kemp Seamount & Calderas Benthic Closed Area	59°40’ – 59°45’ S; 27°45’ – 28°25’W	The seabed, and associated organisms in an area of 352 km2.	The potentially sensitive (largely unknown) benthic fauna of this seamount and caldera. Protects different chemosynthetic habitats, including white smoker vent fields.

South Georgia regions could result in impacts upon the SSI ecosystem despite the fact that commercial krill fishing has never taken place in this region.

The longline fisheries for Patagonian and Antarctic toothfish, which are subject to CCAMLR conservation measures, are further regulated through a range of even more precautionary management measures introduced by the GSGSSI. Since the establishment of the toothfish fishery in 2005, the annual toothfish catch has averaged 80 tonnes, and has been the only commercial fishery removals across the SSI region since the establishment of the Territory’s MZ in 1993. The fishery is constrained by a range of depth and spatial management restrictions to occupy less than 4% of the seabed area within the SSI MZ region.

The establishment of the SGSSI MPA in 2012 and the enhancements added in 2013 and 2019 provide extensive protection measures that ensure the regions unique biodiversity and habitats are conserved. No-Take Zones cover an area exceeding 261,000 km^2, approximately 50% of the eastern half of the SGSSI MZ extending around the SSI. These extensive closed areas, together with GSGSSI fisheries regulations, make the expansion of fisheries in the area highly unlikely. Aside from the impacts of regional climate change, Illegal, Unreported and Unregulated (IUU) fishing remains the greatest threat to the biodiversity of the SGSSI MPA. The strong protections and prohibition measures of the MPA are enforced by GSGSSI through regular patrolling of the area using the Government’s patrol vessel whose activities are supported through access to remote surveillance capabilities provided through the UKs Marine Management Organisation (MMO) and funded in part through the UK Government’s ‘Blue Belt’ Programme. UK maritime patrol flights are routinely conducted over the SSI and provide an additional surveillance capability for this remote region. The presence of a highly regulated fishery provides a seasonal presence in this rarely visited region whilst providing key data on the ecology of target species for local and regional stock assessment and contributes revenue that supports the patrolling and surveillance of the region and without which the SSI would be highly vulnerable to IUU.

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