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Managing Marine Protected Areas in Remote Areas: The Case of the Subantarctic Heard and McDonald Islands

Cassandra M. Brooks[1], Graham Epstein[2] and Natalie C. Ban[3]*

[1] Environmental Studies Program, University of Colorado Boulder, Boulder, CO, United States, [2] Environmental Change and Governance Group, School of Environment, Resources and Sustainability, University of Waterloo, Waterloo, ON, Canada, [3] School of Environmental Studies, University of Victoria, Victoria, BC, Canada

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****Correspondence:***
Cassandra M. Brooks
cassandra.brooks@colorado.edu

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Large marine protected areas (MPAs) are increasingly being established to contribute to global conservation targets but present an immense challenge for managers as they seek to govern human interactions with the environment over a vast geographical expanse. These challenges are further compounded by the remote location of some MPAs, which magnify the costs of management activities. However, large size and remoteness alone may be insufficient to achieve conservation outcomes in the absence of critical management functions such as environmental monitoring and enforcement. The Australian subantarctic Heard Island and McDonald Islands (HIMI) Marine Reserve is among the world's most remote MPAs with notoriously harsh oceanographic conditions, and yet the region's rich mammal and fish resources have been exploited intermittently since the mid-1800s. More recently, the development of lucrative international markets for Patagonian toothfish, sold as Chilean seabass, led to the growth in both legal and illegal fishing. In 2002, to conserve the unique ecology and biodiversity in the area, Australia declared a 65,000 km2 MPA around HIMI. Worldwide, government agencies have, however, struggled to develop cost-effective institutional arrangements for conservation. This paper therefore draws upon the social-ecological systems meta-analysis database (SESMAD) to characterize the structure of conservation governance and outcomes in the HIMI Marine Reserve. The Marine Reserve has generally been successful in supporting a sustainable fishery while addressing threats to biodiversity. The remote and isolated nature of the Marine Reserve was critical to its success, but also benefited greatly from collaborations between managers and the fishing industry. Commercial fishers keep watch over the Reserve while fishing, report any observations of illegal fishing (none since 2006/07), and have at times been asked to verify remote observation of potential illegal fishing vessels. The industry also undertakes annual ecological surveys in the MPA, allowing managers to track environmental trends. The fishing industry itself highlights the importance of industry participation in conservation

planning, strengthened by secure access to resources via statutory fishing rights, which provide critical incentives to invest in conservation. We therefore reflect on the potential application of this case to other remote large MPAs, highlighting potential directions for future research.

Keywords: conservation, common pool resources, marine protected areas, toothfish, subantarctic, Southern Ocean, collaboration, participation

INTRODUCTION

Large marine protected areas (MPAs) are increasingly being established to contribute to global conservation targets (e.g., Gruby et al., 2016), but present an immense challenge for managers as they seek to govern human interactions with the environment over a vast geographical expanse (Wilhelm et al., 2014). These challenges are further compounded by the remote location of some of these MPAs, which result in rapidly rising costs for a range of governance activities, including environmental monitoring and enforcement (Jones and De Santo, 2016). Nonetheless, environmental monitoring and enforcement are fundamental to sustainable environmental governance (Ostrom, 1990; Cox et al., 2010), even in remote areas (Agnew et al., 2009; Muir, 2010) where advances in technology and lucrative resources compel actors to exploit opportunities at the few remaining frontiers of human society (Watson et al., 2015; Tickler et al., 2018). As a result, there is a growing need to better understand strategies for governing large and remote MPAs to protect their unique ecological features and species of conservation concern.

The Australian-governed subantarctic Heard Island and McDonald Islands (HIMI) Marine Reserve, located more than 4,000 km from major human populations (**Figure 1**), is among the world's most remote MPAs. HIMI are among the least disturbed islands in the world and the least impacted islands in the Southern Ocean (e.g., minimum alien species) (IUCN, 2017; Whinam and Shaw, 2018). Heard Island is also one of the only subantarctic islands with a continuously active volcano. HIMI support large breeding populations of marine birds and mammals, and the surrounding waters are prime foraging areas for a number of marine predators that also rely on the land for part of their life-history, including threatened seals and albatross, an endemic cormorant, and four species of penguins (Green and Woehler, 2006; IUCN, 2017). The marine region supports a range of slow-growing and vulnerable benthic organisms (e.g., cold-water corals and sponges), several endemic fish and benthic species, and nursery areas for a range of fish species, including Patagonian toothfish (Dissostichus eleginoides) (Meyer et al., 2000; Duhamel and Welsford, 2011; Welsford et al., 2019).

Despite its remoteness and notoriously harsh oceanographic conditions, the region's rich mammal and fish resources have attracted harvesters since the mid-1800s (Downes and Downes, 2006). More recently the development of lucrative international markets for Patagonian toothfish, sold as Chilean seabass, led to the growth in both legal and illegal fishing around HIMI (Patterson and Skirtun, 2012). In 1997, it was estimated that approximately 70 illegal fishing vessels were operating in the Southern Ocean, and could earn up to a million dollars on a single trip (Baird, 2004).

In 2002, to conserve the unique ecology and biodiversity in the area, Australia declared a 65,000 km2 no-take marine reserve around HIMI (Welsford et al., 2011) (**Figure 2**). Yet due to the remoteness of this area, Australian Government agencies have faced the difficult task in devising cost-effective institutional arrangements for its conservation and management. While these volcanic islands with their rich populations of birds and mammals have attracted scientists since their discovery, the logistics of operations there have proved difficult (Green and Woehler, 2006). A national scientific base was established on Heard Island in 1947, but was abandoned by 1955 (Munro, 2006). Since then scientific operations have been sporadic, with only two dedicated scientific expeditions to the HIMI Marine Reserve since it was designated (in 2003/04 and 2016; Green and Woehler, 2006; AAD, 2019).

Management of the Reserve, including activities such as enforcement, monitoring and research, are a significant challenge for all stakeholders. Indeed, leading up to the time that the MPA was declared, there were growing concerns about illegal, unreported, and unregulated (IUU) fishing in the area, which precipitated an investment of more than AUD $10 million to enhance patrols in the HIMI waters, and where a single trip could cost upwards of AUD $2 million (Baird, 2004). Given the high costs and intermittent nature of funding for enforcement and research, the fishing industry has played an important role in addressing these gaps and contributing to efforts to reduce or minimize threats to biodiversity.

This paper presents a case study of the HIMI Marine Reserve, and the role that legal toothfish fishers have played in its management from the establishment of the Reserve in 2002 until 2012 (a 10-year snapshot). The HIMI Marine Reserve was expanded on 29 March 2014 (to 71,000 km2; with a new Management Plan), the impacts of which are beyond the scope of the current study. Here we build upon a broader effort to systematically code and analyze the design and performance of large-scale MPAs around the world (Ban et al., 2017; Davies et al., 2018). The remainder of this paper is organized in the following way. First, we briefly describe the methods that were used to code and analyze the HIMI Marine Reserve. We then provide a brief history of HIMI as it transformed from a temporary base for sealers in the 1850s onward to one of the world's largest no-take marine reserves. This is followed by an analysis of the critical role that fishers have played in its development, implementation, and performance. We then conclude with a brief discussion about potential insights for

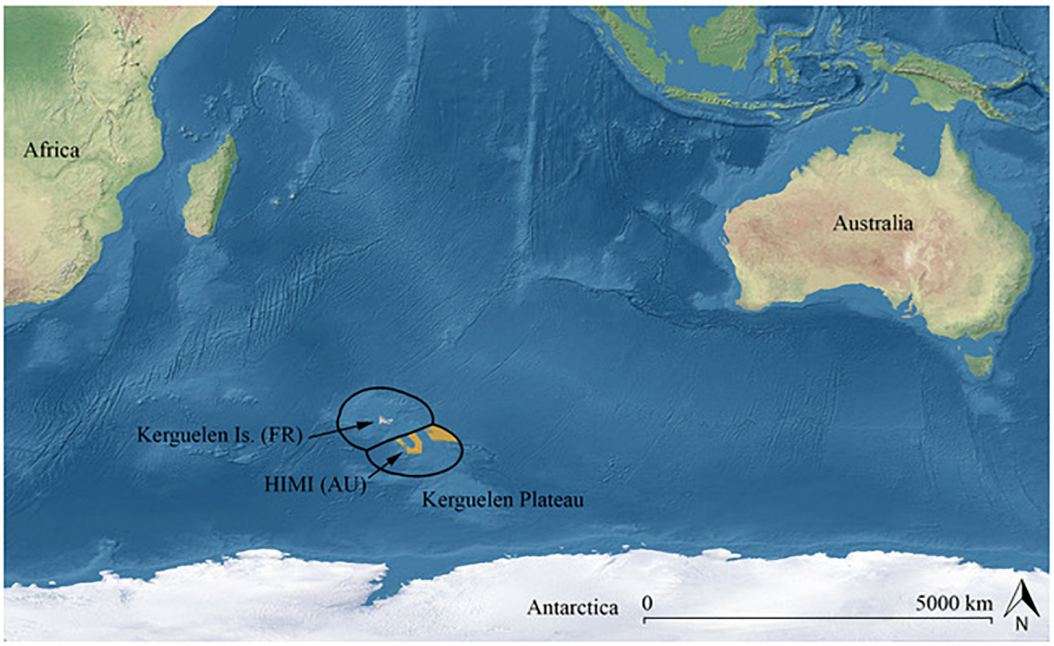

FIGURE 1 | The remote Heard Island and McDonald Islands (HIMI). HIMI are small subantarctic islands on the Kerguelen Plateau located ∼4,000 km southwest of Australia and ∼1,600 km north of Antarctica. The original HIMI Marine Reserve (65,000 km2) is shown in orange (note that the boundaries of the MPA were expanded in 2014). The Australian governed HIMI is adjacent to the French Kerguelen Islands. Australia's Exclusive Economic Zone (EEZ) and the adjacent French EEZ, are illustrated by the black circular lines.

the design and implementation of MPAs in other remote areas around the globe.

MATERIALS AND METHODS

We performed a longitudinal, qualitative, case study (Yin, 2014) of the governance of the HIMI Marine Reserve. A social-ecological systems framework (Ostrom, 2009; Cox, 2014) was used to structure the analysis by identifying key components (resources, actor groups, governance system) of the HIMI Marine Reserve and coding the attributes of those components as part of the collaborative Social-Ecological Systems Meta-Analysis Database (SESMAD) project (Cox, 2014). Through an online platform, SESMAD facilitates systematic collection of information on the social and ecological attributes of large-scale social-ecological systems, the basic unit of analysis, through content analysis of secondary data (e.g., published studies, gray literature) and primary data (e.g., interviews). The SESMAD database provides a simple, and yet powerful approach for systematically coding and analyzing cases through interactions among three core components.

In the HIMI case, we systematically coded (i.e., categorized or indexed) (Saldaña, 2015) variables within the SESMAD database, drawing on extensive peer-reviewed and gray literature to develop an understanding of relevant resources, actors, and the governance systems that influence their interactions with the environment. We analyzed the case between 2002 and 2012, which reflects the establishment of the Reserve in 2002 and our reliance upon secondary data, which often results in a lag between data collection and their broader availability for review. This is consistent with the SESMAD approach and previously published studies using these methods (e.g., Fleischman et al., 2014; Ban et al., 2017). We focused on peer-reviewed studies, and reports and other documentation (policy, legislation, management plans) published by agencies involved in the management of HIMI. We also carried out multiple interviews with three key informants to validate our coding and illuminate important details about governance processes, including the role of different agencies in the management of the HIMI Marine Reserve. We selected participants based on their in-depth experience in research and management of the Marine Reserve. Our study was approved by the University of Victoria's Human Ethics Research Board (ethics protocol number 14-118), and we obtained informed consent from all participants.

We focused on three types of environmental commons in coding the HIMI case study: Patagonian toothfish (Dissostichus eleginoides; the main fishery in the region; environmental commons 1), king penguin (Aptenodytes patagonicus) as an ecosystem indicator (best studied bird in the area, sensitive to climate and environmental changes; environmental commons 2), and light-mantled sooty albatross (Phoebetria palpebrata; long-term presence on HIMI; environmental commons 3) as a migratory species indicator. Two governance systems and three actor groups were also included. The HIMI Marine Reserve Management Plan (governance system 1) governs the land and ocean within the Australian exclusive economic zone (EEZ) around HIMI and is implemented by the Australian

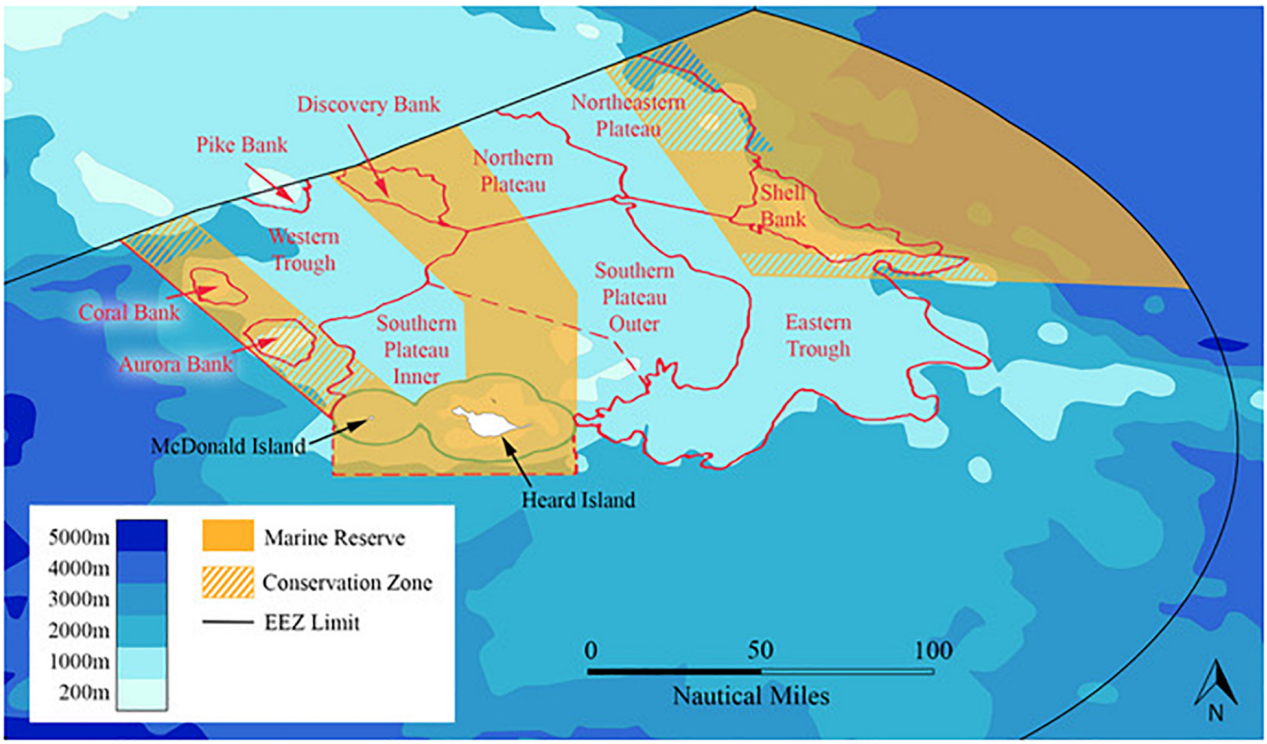

FIGURE 2 | Heard Island and McDonald Islands (HIMI) Marine Reserve and bioregions. Islands represented by white features. Bathymetry (1,000 m increments) is represented by blue coloration (with shallower areas being lighter in color). Red boundaries represent physical units underpinning the marine reserve proposal (based on Meyer et al., 2000). The 2002 HIMI Marine Reserve (65,000 km2) is shown in orange, with no-take areas represented by solid areas and Conservation Zones represented by the hatched areas. Conservation areas underwent further study before some of these regions were incorporated in an expanded HIMI Marine Reserve in 2014 (see text). The HIMI exclusive economic zone boundary is shown by the black line.

Antarctic Division (actor 1). The HIMI Fishery Management Plan (governance system 2), meanwhile, regulates the harvest of toothfish and icefish resources by fishers (actor 2) within the EEZ and is implemented by the Australian Fisheries Management Authority (actor 3). The content of the HIMI MPA case study is publicly available at https://sesmad.dartmouth.edu/ses_cases/18.

RESULTS

Heard Island and McDonald Islands Marine Reserve: Background

Heard Island and McDonald Islands (HIMI) are remote volcanic islands in the South Indian Ocean. Located in one of the most isolated regions of the world, the islands are 1,500 km north of Antarctica and about 4,000 km from Australia, South Africa, and Madagascar (**Figure 1**). The uninhabited islands were discovered in 1853 by American Captain John Heard and were used intermittently as a sealing site between 1856 and the 1880s (Downes and Downes, 2006), with occasional visits by scientific researchers (Green, 2006). By the 1880s, seal populations were decimated, largely ending sealing operations (Downes and Downes, 2006). No nation state claimed HIMI until 1910 when the United Kingdom formally established a claim (Green, 2006). In 1947, with the establishment of an Australian research station on Heard Island, the United Kingdom transferred administration and control of the Islands to the Australian Government (Green, 2006). At that point the islands became governed by Australia as an Australian External Authority through the Heard and McDonald Islands Act of 1953 (Goverment of Australia, 1953).

The Heard Island research station was abandoned in 1955 due to the difficulty and expense of maintenance and operations, and because of the Australian government's priority to support its new Mawson base on the Antarctic continent on the coast of Mac. Robertson Land (Munro, 2006). Since then the islands have been visited only sporadically for research or management (Green and Woehler, 2006; AAD, 2019). Visits by tourists are also only sporadic (see e.g., Heritage Expeditions, 2018). Currently, the most frequent visitor to the area are commercial fishers, which annually target Patagonian toothfish (Dissostichus eleginoides) and mackerel icefish (Champsocephalus gunnari) in the waters around the islands (AFMA, 2018).

In 1979, Australia declared a 200-nautical mile fisheries zone, which in 1994 changed to an official EEZ, abutting France's subantarctic Kerguelen Islands EEZ (Goverment of Australia, 1979, 1994) (**Figure 1**). HIMI also falls within the governance boundaries of the 1980 Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), of which Australia is a signatory (CCAMLR, 1980). The 1991 Australian

Fisheries Management Act regulates all fishing within the HIMI EEZ (Goverment of Australia, 1991).

Australia's commitment under the Convention on Biological Diversity (CBD, 1992) led Australia to develop a National Strategy for the Conservation of Australia's Biological Diversity, which included an objective to develop a national representative system of marine reserves (Goverment of Australia, 1996). In 1996, HIMI (with a 12 nm buffer portion of the surrounding waters) were declared a Wilderness Reserve by Australia (AAD, 1995). In 1997, the islands were then added to the World Heritage List (UNESCO, 1997). During this time, the land and 12 nm ocean portion of the Wilderness Reserve were also managed as an IUCN Category 1a nature reserve (AAD, 1995). In 1998, Australia released their National Oceans Policy, which identified HIMI as one of the five priority areas for inclusion in a national representative system of MPAs (Goverment of Australia, 1998). In 1999 a Strategic Plan for a National System of MPAs was developed (ANZECC TFMPA, 1999). Simultaneously, the Environmental Protection and Biodiversity Conservation Act 1999 entered into force, providing a legal process for establishing and managing marine reserves (Goverment of Australia, 1999). The Federal Government's Environment Australia commissioned the Australian Antarctic Division to complete a comprehensive compilation and review of the conservation values in the marine environment around HIMI (Meyer et al., 2000).

A comprehensive review of the existing geophysical, oceanographic and biological data of the marine region identified 13 distinct physical units within the HIMI EEZ based on a range of physical variables (e.g., bathymetry, sediment characteristics, water temperature, salinity, currents) (Meyer et al., 2000) (**Figure 2**). The proposed reserve design was generally consistent with conservation design principles of being comprehensive, adequate and representative, including a portion of almost all biophysical units. Efforts were made to include areas used by land-based breeding predators, and to provide some connectivity between areas (e.g., to allow juvenile fish migration from shallow nursery to deeper areas) (Welsford et al., 2011). The reserve was also designed with the explicit intent of providing long-term protection in the event of changes in the distribution of species due to climate change (Welsford et al., 2011).

Based on this proposal, after comprehensive stakeholder consultation (described below) a 65,000 km2 HIMI Marine Reserve and Conservation Zone was subsequently established in 2002 (AAD, 2018) (**Figure 2**). The HIMI Marine Reserve Management Plan was developed and entered into force in 2005, establishing rules and regulations for human activities within the Reserve. The Management Plan is administered by the Australian Antarctic Division, but the Division works in collaboration with multiple agencies and other stakeholders – especially the fishing industry – in undertaking research, monitoring, and enforcement (Goverment of Australia, 2005) (**Tables 1**–**3**).

The main purpose of the MPA is to protect: the conservation values of HIMI, including the World Heritage and cultural values; biodiversity; the unique features of the benthic and pelagic environments; representative portions of the different marine habitat types; and marine areas used by land-based marine predators for foraging activities (Goverment of Australia, 2005) (**Table 2**). The MPA is managed as fully no-take. However, fishing, which has occurred since 1997 for toothfish and icefish is allowed in the waters adjacent to the Reserve (Goverment of Australia, 2005).

TABLE 1 | Collaborative management of HIMI Marine Reserve.

Stakeholder/Agency	Role
Australian Antarctic Division	Main management agency
Australian Fisheries Management Authority (in collaboration with others, including the Subantarctic Management Advisory Committee, the Subantarctic Resource Assessment Group, and the Commission for the Conservation of Antarctic Marine Living Resources).	Involved in fisheries and ecosystem management, research and monitoring
Commercial fishers (Austral Fisheries Pty Ltd and Australian Longline Pty Ltd)	Integral to fisheries and ecosystem research and monitoring, IUU deterrent and monitoring
Australian Maritime Safety Authority	Liaise on safety issues
Australian Border Force	Patrolling for IUU fishing, monitoring and enforcement, invasive species issues
Tourist and Recreational Visitors	Opportunistic research and monitoring
French National Authorities	IUU monitoring

Stakeholders and agencies involved in managing the HIMI Marine Reserve and their role in management. IUU refers to illegal, unregulated and unreported fishing.

MPA Performance

Fisheries Outcomes

The HIMI Marine Reserve contributes to the sustainability of the toothfish fishery by protecting aspects of toothfish life history, connectivity and providing opportunities for regular research and monitoring (Meyer et al., 2000; Goverment of Australia, 2002). While currently both icefish and toothfish are harvested in the waters around HIMI, we focus on toothfish since they sustain the largest fishery (Patterson and Skirtun, 2012). While toothfish populations have decreased from about 82% of unfished levels in 2002 to 62% in 2012 (CCAMLR, 2013), this is consistent with the goals of the fishery management plan (AFMA, 2002) and Southern Ocean management thresholds adopted by CCAMLR (Constable et al., 2000). Both fisheries have been certified as sustainable by the Marine Stewardship Council (icefish since 2006; toothfish since 2012) (MSC, 2018) and are considered precautionary and sustainable by Australian Government agencies (Constable and Welsford, 2011; Patterson and Skirtun, 2012; AFMA, 2014).

Fishing regulations are strictly enforced through several monitoring and reporting mechanisms. These include two independent onboard observers, vessel and port monitoring systems, the Australian Fisheries Management Authority or Australian Defense Force patrols, and CCAMLR reporting (AFMA, 2002). Fishers face significant government sanctions for violating rules (including fishing within the MPA) and risk losing their highly coveted Marine Stewardship Council certification, resulting in high levels of compliance (see e.g., AFMA, 2014;

TABLE 2 | Collaboration toward meeting primary management goals.

Management Goal	AAD	AFMA or Fishers	Others
Zoning and IUCN Category (land)	**Active:** via zoning		
Environmental Assessment and Approval (for HIMI visitors/activities)	**Active:** environmental impact assessments required (e.g., land visitors); applications to enter Marine Reserve (e.g., research vessels)		
Visitor Management and Reserve Use	**Passive:** no visitors during snapshot		
– *Access and Transport*			
– *Management of Facilities (land)*	**Passive:** no visitors during snapshot		
– *Visitor Management and Commercial Activities*	**Passive:** no visitors during snapshot		
– *Communicating Reserve Values*	**Active:** via websites		
Natural Heritage Management			
– *Flora and Fauna*	**Mostly Passive:** little to no data on conservation status for many target fauna (e.g., seabirds, mammals); Some assistance from fishery	Assistance with some wildlife conservation issues (e.g., mitigating seabird bycatch)	
– *Natural Asset Use*	**Active:** in partnership	Assistance with ensuring no fishing in Reserve	Border Force and French authorities assist with monitoring for fishing activities
– *Waste Management*	**Passive:** no visitors during snapshot		
– *Prevention and Management of Alien Species and Disease*	**Passive:** no visitors during snapshot		
– *Research and Monitoring*	**Active:** largely in partnership with the fishery	Commercial fishers highly involved with research and monitoring (**Table 3**)	
Cultural Heritage Management	**Active:** Communication goals/prescriptions		
Stakeholders and Partnerships	**Active:** in partnership		
Business Management	**Active:** in partnership		
– *Operational Management*			
– *Compliance and Enforcement*	**Active:** in partnership	Assistance from fishery	Assistance from Border Force and French authorities
– *Financial Management*	**Active:** administrative		
– *Emergency Management*	**Passive:** no visitors during snapshot, but plans in place		
Performance Assessment	**Active:** research that led to conservation zone inclusion (2014 addition)		

Main management goals of the 2005 Heard Island and McDonald Islands (HIMI) Marine Reserve Management Plan (left column) indicating the responsible agency and mechanisms for achieving each goal (center column and right columns). Passive management indicates that the management goal is likely being met, but not by active management by agencies (de facto by no activity or already existing activities). AAD refers to the Australian Antarctic Division. AFMA refers to the Australian Fisheries Management Authority. Note that the HIMI management plan governs the islands and the surrounding Marine Reserve. Empty cells indicate no involvement.

MSC, 2018). With secure access rights, it is also in the fishers' long-term interest to ensure a sustainable and well managed fishery.

While the toothfish populations currently appear sustainable, the fishery operates in a context of significant uncertainty. For instance, there is growing evidence from genetic studies (Appleyard et al., 2002, 2004), parasite faunal analysis (Brickle et al., 2005) and tag recapture studies (Williams et al., 2002; Duhamel and Welsford, 2011) that suggests that HIMI toothfish are part of a larger Kerguelen Plateau/South Indian Ocean population. Recent stock assessments are beginning to incorporate movement between the HIMI and Kerguelen Island regions (WG-FSA, 2017; Ziegler and Welsford, 2019). Further questions, meanwhile, relate to the habitats and locations used for spawning and larval stages, the exact timing of spawning, the proportion of the population that spawns (i.e., evidence of skip-spawning) (Welsford et al., 2012; Péron et al., 2016). From what is known, toothfish are capable of supporting small-scale fisheries, but due to their life history (slow growth, later age at maturity, long-lived) and relatively small populations (Collins et al., 2010), they are vulnerable to overexploitation. For instance, several populations in the region were heavily overexploited by IUU fishers in the 1990s and early 2000s and have yet to recover (McKinlay et al., 2008; Collins et al., 2010; Welsford, 2011).

Toothfish populations in the circumpolar subantarctic region, including HIMI, were subject to extensive IUU fishing from the mid-1990s to early 2000s (Österblom and Sumaila, 2011). However, as a result of efforts by a variety of stakeholders, including the Australian government and the fishing industry (Österblom and Sumaila, 2011; Österblom and Bodin, 2012), there have been no observations of IUU fishing around HIMI since 2005 (AFMA, 2014), and no sightings of IUU vessels in the CCAMLR Area since 2015/16 (CCAMLR, 2017b). Austral Fisheries, an Australian commercial fishing company, were particularly instrumental in recognizing the environmental and economic threats posed by IUU fishing and spent more than $2 million USD in 2002–2003 on lobbying, surveillance, and hiring

TABLE 3 | Participation of commercial fishery in marine reserve research and monitoring.

Research and Monitoring Priorities	Commercial Fishery Participation
Continuing population counts and monitoring of threatened species to assist in the implementation of the subantarctic Fur Seal and Southern Elephant Seal Recovery Plan, Recovery Plan for Albatrosses and Giant Petrels and Draft Recovery Plan for 10 species of seabirds	Observer counts and species identification of seabirds; reporting requirements on any death, injury, or interaction with vessel or gear
Research and Monitoring toward other recovery plans, action plans, and threat abatement plans	Input at Resource Assessment Group and other advisory committee levels; Assistance in preparing potentially successful approaches
Comprehensive surveys of indigenous species to provide baseline information against which to compare human-introduced or otherwise newly colonized terrestrial, freshwater and marine species	Marine species from random stratified trawl survey; also data collection from two fisheries observers; project based research programs
Long-term whole of reserve and colony specific monitoring to provide fundamental data on the distribution, abundance and population trends of seal and seabird species, with particular emphasis on listed threatened species	Fisheries observers conduct counts from vessel while fishing
Surveys to increase knowledge of the biodiversity of the reserve, and its response to current conditions and climate change.	Annual random stratified trawl survey; benthic assemblages sled project, benthic assessment camera work
Hydrographic surveys for producing and updating of marine charts.	Bathymetric data from fishing operations granted upon request (with confidentiality clauses in place); in collaboration with AAD, Universities and Geosciences Australia
Opportunistic monitoring of the distribution of cetaceans during AAD expeditions, by fishing vessels, yachts, tourist vessels, merchant vessels, spotter aircraft	Active monitoring in collaboration with AAD, AFMA observers, Australian and French patrols, scientists, and (occasional) tourist vessels.
Acoustic mapping of the substratum	Active mapping in collaboration with AAD and Universities
Stratified random sampling of the benthos, particularly habitat-forming benthos such as sponges and corals, to determine the extent of differences in the assemblages and habitats between the biophysical units used to develop the reserve	Active sampling in collaboration with AAD and AFMA observers
Stratified random sampling of benthos within and outside the reserve, to determine how well the reserve configuration protects the features it was designed to protect	Active sampling in collaboration with AAD and AFMA observers
Stratified random sampling within and outside the reserve of target species in the HIMI fishery	Active sampling in collaboration with AAD and AFMA observers
Research into the impacts of commercial fishing in adjacent waters on the reserve and/or its key components (e.g., protected species)	Active research via trawl survey, AFMA observers, data collection from vessels, reporting requirements, advisory committees
Monitoring changes in the degree to which anthropogenic threats affect threatened animal species	Some research on environmental variability and some research and management to ensure minimal anthropogenic threats of fishing on seabirds, fish species, ecologically related species
Investigating the cumulative impacts of research programs and other activities on threatened species or species and their habitats that are vulnerable to human disturbance	Ongoing as research programs are undertaken
Fish stock assessments	Substantive involvement with data collection (e.g., from AFMA fisheries observers), participation in advisory committees, and involvement in CCAMLR

HIMI Marine Reserve research and monitoring priorities (Goverment of Australia, 2005) which the commercial fishery participates in (R. Arangio, Austral Fisheries, 29 June 2016; D. Welsford, AAD, 21 October 2016). AAD refers to the Australian Antarctic Division; AFMA refers to the Australian Fisheries Management Authority.

private investigators to identify IUU operators (Österblom and Sumaila, 2011). Austral Fisheries continues to provide support in the form of surveillance, along with the French and Australian governments (R. Arangio, Austral Fisheries, 29 June 2016). They are also an active member of the Coalition of Legal Toothfish Operators (COLTO), a group of 50 toothfish fishing companies and support industry companies from a dozen nations that advocates for legal and environmentally sustainable toothfish fishing operations (COLTO, 2018).

Ecological Outcomes

Habitat assessments have shown that a significant majority of vulnerable organisms occupy the HIMI seafloor at depths of less than 1,200 m, a range that overlaps with the trawl and longline fisheries (Welsford et al., 2014). However, most of the trawling occurs in a relatively small area, which has limited habitat impacts to less than 1.5% of biomass in waters less than 1,200 m (Welsford et al., 2014). Furthermore, the HIMI Marine Reserve contains areas in which 40% or more of the benthic biomass is considered most vulnerable to bottom fishing. However, it has been estimated that only about 0.7% of the seafloor area within the HIMI EEZ has experienced interactions with bottom fishing gear between 1997 and 2013 (Welsford et al., 2014).

Relatively little is known about conservation outcomes for species that rely on the HIMI Marine Reserve. Our analysis focused on two species for which at least some data on their life history and status is available, and which may provide an indicator of ecosystem conditions and role in the life histories of migratory species (Parsons et al., 2008; Einoder, 2009), respectively: king penguin (Aptenodytes patagonicus;

Bost et al., 2013; Cristofari et al., 2018) and light-mantled sooty albatross (Phoebetria palpebrata; Phillips et al., 2016).

King penguins have largely recovered from historical over-exploitations throughout the subantarctic (as an oil source) throughout the region in the late 19th and early 20th centuries (Bost et al., 2013). Populations at Heard Island (as well as Kerguelen) have experienced slower rates of recovery compared to other subantarctic populations, and still appear to be increasing (Woehler, 2006; Bost et al., 2013 and references therein). A 1947 visit to Heard Island, for instance, found only three king penguins, compared to the approximately 80,000 pairs found in 2003/4 (Woehler, 2006). Since then, the available data suggest that the population continues to increase (Heritage Expeditions, 2012; Bost et al., 2013; E. Woehler, BirdLife Tasmania, 28 August 2015); although the lack of a population survey or regular observations since 2003/04 contributes to significant uncertainty about the contemporary population status of king penguins and health of the broader marine ecosystem.

The HIMI Marine Reserve Management Plan addresses a number of threats to king penguins and the marine ecosystem. On land, management zones are used to protect breeding areas, tourists are prohibited from closely approaching and harassing penguins; and scientists require permits to study them (Goverment of Australia, 2005). At sea, meanwhile, some foraging areas fall within the boundaries of the Marine Reserve, but also extend into the French EEZ (around Kerguelen) and into the high seas (see e.g., Meyer et al., 2000). King penguins forage at great depths (reaching 440 m) and feed on pelagic fish, especially myctophids (Moore et al., 1999; Bost et al., 2013). If myctophids are not readily available, king penguins may also feed on mackerel icefish – a species which is also commercially harvested outside the boundaries of the Marine Reserve, thus potentially putting penguins in competition with commercial fishers (Bost et al., 2013). King penguins travel far, especially in the winter (up to 1,800 km from their colony, 5,000 km round trip) (Putz et al., 1999). However, during the breeding season, they typically stay within 500 km of their colonies (Putz et al., 1999). Their foraging ecology has been extensively studied and is strongly dependent on the Antarctic frontal zone features, especially the Antarctic Polar Front (Bost et al., 2015; Cristofari et al., 2018). This makes them highly vulnerable to climate change (Peron et al., 2012; Bost et al., 2013, 2015; Cristofari et al., 2018). Shifts in their main prey, myctophids, are predicted under future climate change scenarios, with unknown consequences for king penguins (Freer et al., 2019).

The MPA was explicitly designed with the intent of protecting breeding sites and foraging grounds for migratory seabirds, including light-mantled sooty albatross (Meyer et al., 2000; Goverment of Australia, 2005). These circumpolar birds can travel more than 6,000 km from breeding sites (including sites on Heard Island) to their foraging grounds (Weimerskirch and Robertson, 1994). Light-mantled sooty albatrosses demonstrate high breeding site fidelity but because they are biennial breeders, they do not return each year (Bonnevie et al., 2012). The population at Heard Island has been estimated at somewhere between 200 and 500 nesting pairs based upon 2000/01 and 2003/4 surveys (Green and Woehler, 2006; Woehler, 2006). This population is relatively stable based on comparisons with early counts from the 1950s which also estimated between 200–500 pairs (Downes et al., 1959). Historical trends and expert interview (E. Woehler, BirdLife Tasmania, 28 August 2015) suggest the population is stable or increasing, the latter being due to the novel nesting sites found since the 1950s (Woehler, 2006). Counts by tourists in 2012 also support estimates of a persistent population (Heritage Expeditions, 2018). However, accessibility and changes in nesting locations pose significant challenges for obtaining a reliable estimate of the breeding population (Woehler, 2006).

The HIMI Marine Reserve Management Plan addresses a number of potential threats to light-mantled sooty albatross on land and sea portions of the Reserve. This includes requirements for visitor permits, restrictive zoning of land areas to concentrate impacts and avoid nesting areas; and prohibitions against fishing in the Reserve (Goverment of Australia, 2005). Protection of land areas has been greatly facilitated by isolation. However light-mantled sooty albatross breeding at HIMI continue to face significant threats emerging from beyond the boundaries of the Reserve. These include climate change and incidental mortality in legal and IUU fisheries for tuna and toothfish (ACAP, 2012; Phillips et al., 2016; BirdLife International, 2018). However, the toothfish fishery at HIMI has proved remarkably successful in avoiding such impacts through the adoption of innovative technologies and mitigation measures (AFMA, 2014). Since 2006, very few birds (1–7 per year) are taken in the toothfish fishery at HIMI, none of which were light-mantled sooty albatross (CCAMLR, 2017a).

HIMI: Factors Contributing to Conservation Success

HIMI has been offered as an example of successful marine conservation in a remote and challenging environment (Constable and Welsford, 2011; Goldsworthy et al., 2016; MSC, 2018). Our case study indicates that the success of the HIMI Marine Reserve stems from two critical factors: (1) remoteness and isolation which reduce human threats and impacts, and (2) collaboration with the fishing industry, which has allowed stakeholders to manage threats posed by the fishing industry and provide an efficient approach for addressing management gaps.

Remoteness

The remoteness of HIMI and the harsh climate it experiences have made significant contributions to the protection of biodiversity on land and marine areas, by limiting direct human interactions with the environment since sealing and whaling activities ceased in the early 20th century (Green and Woehler, 2006; IUCN, 2017; Whinam and Shaw, 2018). Since the 1960s, Heard Island has experienced mostly sporadic visits from scientists and tourists, while McDonald Island has only been visited on two occasions (AAD, 2018). While isolation offers significant protection from a number of threats, it also poses significant challenges for managing the Reserve and responding to emerging threats (Whinam and Shaw, 2018). A lack of funding and logistical support by the Australian Antarctic Division and the high costs of traveling to HIMI have prevented managers

from undertaking activities specified in management plans, such as ecological monitoring which could provide important details about the status and trends for species of conservation concern (see **Tables 2**, **3**).

The remoteness and difficulty of access also means that managers know very little about the status of marine life, with the exception of targeted commercial fish species, around HIMI (IUCN, 2017; **Tables 2**, **3**). Similarly, satellite imaging of Heard Island has revealed significant glacial retreat (see e.g., Mitchell and Schmeider, 2017; AAD, 2018), but scientists and managers currently lack an understanding of the potential impacts of these changes (and other climate change impacts) on birds and mammals on the island (Chambers et al., 2013, 2014). Climate change has caused phenological changes in many other Southern Ocean seabirds, especially penguins and some albatrosses, including species that live on HIMI (Chambers et al., 2013, 2014). Finally, although there is no indication that climate change has adversely affected HIMI toothfish populations as of yet, toothfish recruitment may be sensitive to changes in sea surface temperature and could be affected by predicted future changes (Trathan and Agnew, 2010; Constable et al., 2014).

Collaboration With the Fishing Industry

Australia adopted a highly transparent and collaborative process for developing the HIMI MPA, including opportunities for significant participation by the fishing industry. After reviewing ecological values in the area and proposing an MPA design that followed best practices in conservation (Meyer et al., 2000), the Australian Antarctic Division released the proposal in early 2001 and began an extensive (18-month) consultation process which included the formation of the HIMI stakeholder group (Welsford et al., 2011; Goldsworthy et al., 2016). This group included members from the policy and research branches of the Australian Antarctic Division, the fishing industry and a variety of non-governmental organizations. After consultation, the stakeholder group largely supported the design and rationale for the MPA proposal and they supported inclusion of approximately 85% of the original proposal (Welsford et al., 2011). The HIMI stakeholder group, chose to temporarily set some of the proposed areas as "Conservation Zones" which allowed for further research on the conservation values of these areas against the representativeness of other areas in the MPA as well as for examining the threat of fishing to the conservation values in this area against the economic importance of the fishery (Welsford et al., 2011). The HIMI Marine Reserve was subsequently established in 2002 as a 65,000 km2 no-take (IUCN category Ia) MPA (**Figure 2**), and parts of these conservation zones were incorporated into the expanded Marine Reserve in 2014.

This transparent process resulted in strong support by the fishing industry, which consists of only two companies: Austral Fisheries and Australian Longline. In 2003, Austral Fisheries received an award from the World Wildlife Fund for their involvement in the HIMI and the Macquarie Island Marine Reserves (Austral Fisheries, 2018). The fishing companies have strongly supported the HIMI Marine Reserve and believe it contributes to a stronger and more sustainable fisheries management system.

> *"We have a strong belief in the science that underpins the fishery and we know what can happen if it's not managed properly. The end game is a balance between protection and rational use and we supported the MPA because we knew it would protect benthic assemblages, juvenile fish stocks and create broader ecosystem balance"*
>
> *(R. Arangio, Austral Fisheries, 29 June 2016).*

The two toothfish fishing companies hold individual transferable quotas that provide a secure and long-term right to harvest toothfish resources at HIMI. Although there are a number of important exceptions (see e.g., Ban et al., 2009), individual transferable quotas can provide critical incentives to support the long-term sustainability in fisheries (Grafton et al., 2006; Costello et al., 2008, 2010).

The collaboration between the Australian Antarctic Division and the fishing industry early on lent itself to collaborative management. Moreover, the Australian Fisheries Management Authority employs a 'partnership approach' in their fisheries management (Smith et al., 1999). As was exemplified in the HIMI Marine Reserve process, fisheries management in Australia emphasizes stakeholder involvement in all key area of fisheries management, including stock assessment, research priorities, enforcement and decision-making (Smith et al., 1999). In the case of HIMI, while the Australian Antarctic Division and the Australian Fisheries Management Authority (the government agency which oversees fisheries) are separate bodies with separate mandates and management plans, they work very closely in the management of the HIMI Marine Reserve (see e.g., AFMA, 2002; Goverment of Australia, 2005) (**Tables 2**, **3**). The fishing industry also has an agreement to monitor the MPA, which is complemented by a vessel monitoring system and remote surveillance by the governments of Australia and France via satellites. Ultimately, activities occurring within and adjacent to the MPA are actively monitored, and there are no indications of IUU fishing or other prohibited activities occurring within the HIMI EEZ since 2005 (AFMA, 2014).

HIMI Marine Reserve Management

Australia's Antarctic Territories, including HIMI, are managed by the Australian Antarctic Division, which often struggles with limited resources and fiscal constraints that create challenges for research and monitoring in the HIMI Marine Reserve. As a result, the Division has relied heavily on partners, including the fishing industry, to assist in research and monitoring (**Tables 1**–**3**). Minor assistance is also provided by the Australian Department of Defense, tourists, and French national authorities who actively undertake research and patrols in the Kerguelen and Crozet EEZ (**Table 1**). The Australian Antarctic Division issues permits for the rare visitors, manages flora and fauna, and monitors compliance with fishing regulations. Management of the Reserve is largely passive in the sense that there is a limited human presence beyond fishing (**Table 2**). In the time since the Reserve was established in 2002, there has only been two dedicated science expeditions to the HIMI Marine Reserve – one in 2003/04 and one in 2016. Two private tourism expeditions have visited the Reserve (in 2012 and 2016) and the Australian Antarctic Division has had one management visit (in 2008) (AAD, 2019). Some

research and monitoring is done remotely (e.g., via satellites), while the majority is undertaken in collaboration with the fishing industry (**Tables 2**, **3**). Monitoring for fishing activity is undertaken via satellites, through government vessel patrols (in collaboration with the French Government) and in collaboration with the fishing industry. Other organizations provide support in the form of information (e.g., CCAMLR, COLTO), monitoring, and enforcement (e.g., surveillance carried out by the Australian Border Force) (**Tables 1**–**3**).

Institutional Arrangements With the Fishing Industry

Environmental monitoring for the HIMI Marine Reserve and the broader HIMI EEZ takes place in the context of the "fishery assessment plan," a formal agreement between the Australian Antarctic Division with the Australian Fisheries Management Authority that specifies research activities and responsibilities on an annual basis (D. Welsford, AAD, 21 October 2016; R. Arangio, Austral Fisheries, 29 June 2016). Permits for research activities in the HIMI Marine Reserve (including fish surveys) are issued by the Australian Fisheries Management Authority in consultation with the Australian Antarctic Division (Welsford et al., 2011). The fishing industry is primarily responsible for *ad hoc* monitoring via fisheries observers on vessels and for undertaking the annual random stratified trawl survey (see below; D. Welsford, AAD, 21 October 2016). However, apart from research activities and transit, the fishing industry is strictly prohibited from entering the Marine Reserve (Goverment of Australia, 2005; R. Arangio, Austral Fisheries, 29 June 2016).

While the Australian Antarctic Division leads stock assessment work, the fishing industry carries out supportive research and monitoring on an annual basis, the costs of which it is not compensated for. The Australian Fisheries Management Authority policy is that the industry provides in-kind support (equivalent to about $600,000 AUD) for the stratified survey alone (D. Welsford, AAD, 21 October 2016). These are the conditions agreed to for entry into the fishery. Industry also pay for fish tagging (D. Welsford, AAD, 21 October 2016), which includes both the cost of the tag, but also the opportunity cost of the released fish. Two fisheries observers, which are required to be on board at all times, are also funded by industry. Industry may also take a third observer to assist with completing surveys or required research from time to time. Industry costs are generally shared between the two fishing companies as a proportion of the fishing quota holdings (R. Arangio, Austral Fisheries, 29 June 2016).

Fishing Role and Activities

Random stratified trawl survey

Since 1997, commencing with the start of the commercial fishery for toothfish and icefish, the fishing industry has undertaken an annual Random Stratified Trawl Survey, typically occurring in April-May (AFMA, 2014). The survey covers 10 regions (strata) of the Heard Island Plateau that define areas of similar depth and/or fish abundance. The annual surveys have continued since the establishment of the MPA and routinely incorporate stations inside and outside the boundaries of the MPA (Welsford et al., 2011). Approximately 20 days of the industry fishing time is provided to complete the survey (R. Arangio, Austral Fisheries, 29 June 2016). The Australian Antarctic Division provides a specific set of instruments for the survey, in addition to tow times, tow directions, and a list of stations randomly dotted across the plateau. Approximately 15–20% of the 160 stations are found in the MPA (R. Arangio, Austral Fisheries, 29 June 2016). The survey is conducted by Austral Fisheries, on behalf of the two fishing companies that own quota in the HIMI toothfish fishery (Austral Fisheries and Australian Longline) (R. Arangio, Austral Fisheries, 29 June 2016).

Benthic survey

The fishing industry (Austral Fisheries) has also undertaken specific monitoring and survey work to assist the Australian Antarctic Division in past years, including benthic sampling with towed sleds (R. Arangio, Austral Fisheries, 29 June 2016). In 2003 a benthic beam trawl and sled sampling occurred as part of an Australian Antarctic Division and fishing industry funded research project to evaluate the biodiversity inside and outside the Reserve and Conservation Zone. Further work was undertaken in 2007/8 as part of a large collaborative project involving the Division, the fishing industry, the Australian Fisheries Management Authority and the Fisheries Research and Development Corporation, and continued until 2013. The research project involved video habitat monitoring to identify and evaluate benthic assemblages in the HIMI area. Cameras were mounted on trawl gear, longlines, and pots. The video information was combined with habitat mapping and analyses of regional community structures (R. Arangio, Austral Fisheries, 29 June 2016). The resulting study found that more than 98% of habitat was unaffected by fishing and offered further knowledge of the region, including areas within the MPA (Welsford et al., 2014).

Seabird monitoring and technical innovation

While the MPA explicitly includes provisions for migratory species, including foraging areas for albatross (Goverment of Australia, 2005), the primary threat to these birds is incidental bycatch by commercial fishing vessels. In accordance with the HIMI Fishery Management Plan (2002), the fishing industry must implement several seabird bycatch mitigation measures. Internally weighted lines, which are now a global standard for automatic longline fishing vessels allow hooks to sink rapidly out of reach from seabirds (Wiedenfeld, 2016). HIMI fishers use these weighted lines combined with tori lines and brickle curtains on every haul and this combination has minimized seabird interactions (AFMA, 2002, 2014). The fishers also follow restrictions on time of day for setting gear to avoid seabird interactions as well as seasonal closures. The release of offal is prohibited to avoid attracting seabirds to fishing vessels (AFMA, 2002). Each vessel must also have two full time observers (AFMA, 2002). These observers maintain daily records that outline the number and types of seabirds observed while fishing. Further, they are required to report any physical interactions between fishing activities and seabirds (AFMA, 2002, 2014). Australian and New Zealand toothfish fishers have also contributed to the development of innovative technologies designed to reduce

threats to seabirds (R. Arangio, Austral Fisheries, 29 June 2016). These seabird bycatch mitigation measures are in accordance with the current scientific consensus and are considered perhaps the best example of seabird bycatch mitigation techniques (see e.g., Croxall, 2008; Wiedenfeld, 2016).

Social monitoring (IUU)

The rapid growth of IUU fishing for toothfish in the late 1990s and early 2000s contributed to the establishment of COLTO (Österblom and Sumaila, 2011). COLTO, along with dozens of other governmental and non-governmental organizations, have worked to dramatically reduce IUU fishing throughout the Southern Ocean, including around the Heard and McDonald Islands (Österblom and Sumaila, 2011). Crew and fisheries observers on commercial fishing vessels have played an important role in these efforts by monitoring for and reporting observations of potential IUU vessels. Crew members report observations directly back to the fishing company (e.g., Austral Fisheries) while the fisheries observer records any vessel sightings and provides this information to the Australian Fisheries Management Authority, the Australian Antarctic Division and CCAMLR (R. Arangio, Austral Fisheries, 29 June 2016). Further, Australia has signed a memorandum of understanding with the French Government for joint patrols and surveillance over the Kerguelen Plateau, which can be undertaken from French or Australian patrol vessels (R. Arangio, Austral fisheries, 29 June 2016). Since 2005, through the joint efforts of the fishing industry, French and Australian Governments, there have been no reports of IUU fishing within the HIMI EEZ (AFMA, 2014).

Fisheries and Fisheries Management Near HIMI

Fisheries in the HIMI EEZ are managed by the Australian Fisheries Management Authority, under the Fisheries Management Act 1991 (Goverment of Australia, 1991) in close cooperation with the Australian Antarctic Division and in accordance with Conservation Measures set by CCAMLR (AFMA, 2014). The HIMI Fishery Management Plan includes the trawl fishery for mackerel icefish and the trawl, longline and pot fisheries for Patagonian toothfish (AFMA, 2002). Longlines were introduced in 2003 and pots were introduced in 2009, though fishing via pots remains at a very low level. The total allowable catch for toothfish between 2002 and 2012 has ranged between 2400–2800 tones (with pots comprising only 30–68 tons) (CCAMLR, 2017a). The toothfish fishery has gradually shifted from trawls to longline (e.g., in 2012 about half the total allowable catch was caught via trawl, but by 2017 it was only 24 tons) (AFMA, 2014) as innovations in longline technology have reduced threats to seabirds (AFMA, 2014; CCAMLR, 2017a). In addition, the Antarctic Marine Living Resources Conservation Act 1981 (Goverment of Australia, 1981), administered by the Australian Antarctic Division, implements Australia's international obligations under the Commission for the Conservation of Antarctic Marine Living Resources (AFMA, 2014).

With regards to Patagonian toothfish, the HIMI Fishery Management Plan establishes rules for setting catch limits, granting fishery quotas, and implementing other fisheries and environmental measures (e.g., gear restrictions, bycatch rules) (AFMA, 2002). The plan is implemented primarily by the Australian Fisheries Management Authority who cooperates with the Australian Antarctic Division to avoid potential impacts on the MPA and ensures consistency with CCAMLR Conservation Measures. The Australian Fisheries Management Authority aims to maintain toothfish populations at sustainable levels, while also attempting to avoid impacts on the broader ecosystem through limits on bycatch and mitigation measures to avoid interactions with seabirds (AFMA, 2002, 2014).

The HIMI fishery is managed using transferable quotas, which are currently held by two Australian fishing companies: Austral Fisheries (71% of fishing rights) and Australian Longline (29% of fishing rights) (R. Arangio, Austral Fisheries, 29 June 2016). Until the 2011/12 season, three or four vessels were in operation per season at HIMI (CCAMLR, 2018). Through consultative fora, toothfish fishers play an active role in the governance and management of toothfish (e.g., through industry representatives at SouthMAC – the Subantarctic Fisheries Management Advisory Committee and SARAG – the Subantarctic Resource Assessment Group – which includes representatives from the fishing industry, conservation groups, scientists and other relevant experts) (AFMA, 2014). Based on advice from SARAG, SouthMAC recommends catch rules to AFMA. Mechanisms are also in place to manage perceived or actual conflicts of interest by members of these groups when they are developing their advice. These fora, along with engagement via COLTO, provide mechanisms for conflict resolution and building trust through repeated face to face interactions (Ostrom et al., 1994).

DISCUSSION

The HIMI Marine Reserve and the role that toothfish fishers have played in its establishment, implementation and management, and its success in managing threats and supporting conservation efforts are a remarkable example of the benefits of participatory conservation planning. The toothfish fishers have made significant efforts to develop technologies and adjust operations to reduce seabird bycatch, and have made a number of critical contributions to the governance of the Reserve, including surveillance and environmental monitoring. This case clearly demonstrates the potential value of adopting participatory conservation models that view resource users not only as a potential threat to the environment, but also as a critical partner for achieving conservation goals (Stoll-Kleemann and O'Riordan, 2011; Andrade and Rhodes, 2012). Toothfish fishers were engaged in the early stages of conservation planning, their input was respected and incorporated in the form of temporary conservation zones, and as a result the fishers have continued to support the Reserve through a range of activities and actions. The HIMI Marine Reserve presents

a potentially valuable model that can inform conservation planning, although important questions remain concerning the contexts in which similar approaches are more (or less) likely to prove effective. In particular, the success of participatory conservation planning at HIMI may have been facilitated by a number of critically important enabling conditions that contributed to its success.

First and perhaps foremost, the HIMI Marine Reserve was established in the context of political debates surrounding IUU fishing of toothfish and the potential impacts of Antarctic fisheries in general on what is seen by many as a 'pristine' environment (Potts and Haward, 2006; Stokstad, 2010; Cavanagh et al., 2016). These debates and the potential threats they pose to the livelihoods of the fishers have likely motivated them to invest in efforts to avoid, minimize, or mitigate their impacts on the broader marine environment. Furthermore, the HIMI fishery is a high-valued resource that is currently exploited by a low number of users (two companies) that possess secure and long-term rights to the resource. Small group size is generally thought to facilitate efforts to negotiate and implement agreements by reducing transaction costs (Olson, 1965); while secure property rights and the economic value of toothfish provide incentives to invest in the long-term sustainability of a resource (Ostrom, 1990; Grafton et al., 2006). These factors are clearly highlighted as critical by the fishers themselves:

> *"It [managing the MPA] involves lots of collaboration and cooperation between all parties, and a good understanding of the goals and attributes of MPAs. One powerful benefit available in the HIMI fishery, but not available in (for example) high seas fisheries, is the granting of secure, long term, fishing access rights. That also has a considerable impact on helping to focus on the longer term benefits of conservation and protection, as opposed to being constantly worried about 'will I have access next year' which, clearly, engenders a more short-term response and approach"*
>
> *(R. Arangio, Austral Fisheries, 29 June 2016).*

In other remote protected regions, meanwhile, such as the newly adopted Ross Sea region MPA in Antarctica, fisheries are competitive in that all fishing vessels lack individually assigned quotas and instead race to fish until the total quota is captured (Reid, 2019). While the Ross Sea region MPA planning process did include some fishing industry stakeholders, and the adopted MPA does accommodate commercial fisheries, it is unclear if the fishing industry will have similar incentives to participate in research and monitoring as at HIMI. Up to 16 different fishing companies from nine different fishing nation states compete for fisheries resources in the Ross Sea (CCAMLR, 2019). The race to fish is often cited as a core driver of overexploitation in fisheries, with corresponding impacts on the environment and the people that depend upon them (Grafton et al., 2006; Branch, 2009). As a result, it is unclear if participation alone will be sufficient to achieve similar results in the Ross Sea.

Second, although the remote nature of the HIMI Marine Reserve has certainly contributed to its success by limiting direct human interactions with the environment; human impacts on the prevailing climate regime are a growing threat to the HIMI Marine Reserve and the species it protects (IUCN, 2017; Whinam and Shaw, 2018). Because of the islands' location in the subantarctic region, occurring within the path of major circumpolar fronts, both the land and sea systems are highly vulnerable to climate change. King penguins and other species on HIMI, for instance, have depended upon foraging grounds located along these fronts (e.g., Peron et al., 2012; Bost et al., 2013). The environmental monitoring system supported by toothfish fishers and tourists which provides merely *ad hoc* monitoring of many species (with the notable exception of monitoring of toothfish and benthic surveys), may be insufficient to detect and respond appropriately to emerging threats from climate change. As a result, although the efforts of the toothfish fishers are to be commended, further support from government stakeholders for scientific surveys on land and in the sea may be necessary to ensure the long-term sustainability of the HIMI ecosystem.

CONCLUSION

The global push for large MPAs have led to an increasing number of relatively vast and remote protected areas that pose significant management, research, and monitoring challenges. Here we presented a unique case of the HIMI Marine Reserve – one of the most remote MPAs on earth and relatively large at 65,000 km2 (since expanded to 71,000 km2) – and the collaborative management between the Australian Government and fishing industry in meeting the objectives of the Reserve. The Reserve has generally been successful at both supporting sustainable fisheries while also conserving biodiversity. Importantly, the Reserve has in part met its goals through being remote and isolated; little to no humans regularly visit the HIMI region besides commercial fishers. The fishers are prohibited from fishing in the Reserve and demonstrate high compliance, as a result of several factors – their involvement with zoning of the MPA, their desire to keep their exclusive quotas for lucrative toothfish, as well as both companies striving to be good corporate citizens (for example Austral Fisheries are, to date, the only certified carbon neutral fishing business in the world). The early involvement of the fishing industry in the MPA process facilitated continued collaboration throughout management; the industry invests in research and monitoring to support the objectives of the Reserve while also aiding in monitoring and reporting any illegal fishing activities. However, mainly due to lack of capacity by the Australian Government, research, management and enforcement is largely passive with very little information on the status of species and ecosystems around HIMI. Given the future threat of climate change, current management may be insufficient at conserving the HIMI marine ecosystem. Additional support is needed from government, scientists and other stakeholders. Further, while this model works relatively well at HIMI, it may not apply to other remote MPAs. Only two companies fish in the HIMI EEZ and they have exclusive quota rights. In contrast in other remote

MPAs, e.g. the Ross Sea, where more than a dozen companies compete to fish in 'Olympic-style' fisheries, all vessels involved compete for the available catch. Further, while the collaborative management between fishers and the Australian government has arguably been a success, it may not be enough to manage for future environmental change, invasive species or other threats.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the manuscript and online at https://sesmad.dartmouth.edu/ses_cases/18.

ETHICS STATEMENT

The committee is the University of Victoria Human Ethics Research Board. Procedure: We obtained informed consent from all participants. As interviews were done remotely via telephone and/or through email exchanges, we obtained verbal informed consent during interviews, and written consent in email exchanges. All participants reviewed the manuscript and approved the use of their names, organizations, and quotes where relevant.

AUTHOR CONTRIBUTIONS

CB, GE, and NB designed the research. CB and GE carried out the research, including interviews, and conducted the analyses. All authors wrote the manuscript.

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REFERENCES

AAD, (1995). *"Heard Island Wilderness Reserve Management Plan", Australian Antarctic Division*. Canberra, ACT: National Library of Australia.

AAD, (2018). *Heard Island & McDonald Islands*. Available: http://heardisland.antarctica.gov.au (accessed March 1, 2019).

AAD, (2019). *Personal Communication with Australian Antarctic Division via email*. Available at: http://www.antarctica.gov.au/living-and-working/training (accessed April, 07 2019).

ACAP, (2012). *Light-Mantled Albatross Phoebetria Palpebrata*. Sydney, NSW: ACAP.

AFMA, (2002). *Heard Island and McDonald Islands Fishery Management Plan 2002 A.F.M*. Canberra, AU: Australian Fisheries Management Authority and the Office of Legislative Drafting and Publishing.

AFMA, (2014). *Status report: Heard Island and McDonald Islands Fishery*. Canberra, AU: Australian Fisheries Management Authority.

AFMA, (2018). *Heard Island and McDonald Islands Fishery*. Available: https://www.afma.gov.au/fisheries/heard-island-mcdonald-island-fishery (accessed March 1, 2019).

Agnew, D. J., Pearce, J., Pramod, G., Peatman, T., Watson, R., Beddington, J. R., et al. (2009). Estimating the worldwide extent of illegal fishing. *PLoS One* 4:e4570. doi: 10.1371/journal.pone.0004570.t001

Andrade, G. S. M., and Rhodes, J. R. (2012). Protected areas and local communities: an inevitable partnership toward successful conservation strategies? *Ecol. Soc.* 17:14. doi: 10.5751/es-05216-170414

ANZECC TFMPA, (1999). *Strategic Plan of Action for the National Representative System of Marine Protected Areas: A guide for Action by Australian Governments*. Canberra, ACT: ANZECC TFMPA.

Appleyard, S. A., Ward, R. D., and Williams, R. (2002). Population structure of the patagonian toothfish around heard, mcdonald and macquarie islands. *Antarctic Sci.* 14, 364–373. doi: 10.1017/s0954102002000238

Appleyard, S. A., Williams, R., and Ward, R. D. (2004). Population genetic structure of patagonian toothfish in the west indian ocean sector of the southern ocean. *CCAMLR Sci.* 11, 21–32.

Baird, R. (2004). Coastal state fisheries management: a review of australian enforcement action in the heard and mcdonald islands australian fishing zone. *Deakin L. Rev.* 9:91.

Ban, N. C., Caldwell, I. R., Green, T. L., Morgan, S. K., O'Donnell, K., and Selgrath, J. C. (2009). Diverse Fisheries Require Diverse Solutions. *Science* 323:338. doi: 10.1126/science.323.5912.338

Ban, N. C., Davies, T., Aguilera, S., Brooks, C., Cox, M., Epstein, G., et al. (2017). Social and ecological effectiveness of large marine protected areas. *Glob. Environ. Change* 43, 82–91. doi: 10.1371/journal.pone.0050074

BirdLife International. (2018). *Phoebetria Palpebrata. The IUCN Red List of Threatened Species 2018: e.T22698448A132647449*. Available: http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22698448A132647449.en (accessed March 20, 2019).

Bonnevie, B. T., Connan, M., and McQuaid, C. D. (2012). Effects of re-breeding rates on population size estimation of biennial breeders: results from a model based on albatrosses. *IBIS* 154, 499–507. doi: 10.1111/j.1474-919x.2012.01247.x

Bost, C. A., Cotte, C., Terray, P., Barbraud, C., Bon, C., Delord, K., et al. (2015). Large-scale climatic anomalies affect marine predator foraging behaviour and demography. *Nat. Commun.* 6:8220. doi: 10.1038/ncomms9220

Bost, C.-A., DeLord, K., Barbraud, C., Cherel, Y., Putz, K., Cotte, C., et al. (2013). "King Penguin," in *Penguins: Natural History and Conservation*, eds P. Garcia, and P. D. Boersma, (Seattle, WA: University of Washington Press), 7–22.

Branch, T. A. (2009). How do individual transferable quotas affect marine ecosystems? *Fish Fisher.* 10, 39–57. doi: 10.1111/j.1467-2979.2008.00294.x

Brickle, P., MacKenzie, K., and Pike, A. (2005). Parasites of the patagonian toothfish, dissostichus eleginoides smitt 1898, in different parts of the subantarctic. *Polar Biol.* 28, 663–671. doi: 10.1007/s00300-005-0737-732

Cavanagh, R. D., Hill, S. L., Knowland, C. A., and Grant, S. M. (2016). Stakeholder perspectives on ecosystem-based management of the antarctic krill fishery. *Mar. Policy* 68, 205–211. doi: 10.1016/j.marpol.2016.03.006

CBD, (1992). *Convention on Biological Diversity*. New York, NY: United Nations.

CCAMLR, (1980). *The Convention on the Conservation of Marine Living Resources*. Hobart, TAS: CCAMLR.

CCAMLR, (2013). *Fishery Report 2013: Dissostichus Eleginoides Heard Island Australian EEZ (Division 58.5.2)*. Hobart, TAS: CCAMLR.

CCAMLR, (2017a). *Fishery Report 2017: Dissostichus Eleginoides Heard Island Australian EEZ (Division 58.5.2)*. Hobart,TAS: CCAMLR.

CCAMLR, (2017b). *Report of the XXXVI Meeting of the Commission*. Hobart, TAS: CCAMLR.

CCAMLR, (2018). *Fisheries Reports Archive*. Available: https://www.ccamlr.org/en/publications/fishery-reports-archive (accessed March 21, 2019).

CCAMLR, (2019). *List of Authorised Vessels*. Available: https://www.ccamlr.org/en/compliance/list-vessel-authorisations (accessed March 22, 2019).

Chambers, L. E., Altwegg, R., Barbraud, C., Barnard, P., Beaumont, L. J., Crawford, R. J., et al. (2013). Phenological changes in the southern hemisphere. *PLoS One* 8:e75514. doi: 10.1371/journal.pone.0075514

Chambers, L. E., Dann, P., Cannell, B., and Woehler, E. J. (2014). Climate as a driver of phenological change in southern seabirds. *Int. J. Biometeorol.* 58, 603–612. doi: 10.1007/s00484-013-0711-716

Collins, M. A., Brickle, P., Brown, J., and Belchier, M. (2010). "The Patagonian Toothfish: Biology, Ecology and Fishery," in *Advances in Marine Biology*, ed. M. Lesser, (Cambridge, MA: Academic Press), 227–3000.

COLTO, (2018). *COLTO- The Coalition of Legal Toothfish Operators*. Available: https://www.colto.org (accessed March 18, 2019).

Constable, A., de la Mare, W., Agnew, D., Everson, I., and Miller, D. (2000). Managing fisheries to conserve the antarctic marine ecosystem: practical implementation of the convention on the conservation of antarctic marine living resources (CCAMLR). *ICES J. Mar. Sci.* 57, 778–791. doi: 10.1006/jmsc.2000.0725

Constable, A., and Welsford, D. (2011). "Developing a precautionary ecosystem approach to managing fisheries and other marine activities at heard island and mcdonald islands in the indian sector of the southern ocean," in *The Kerguelen Plateau: Marine Ecosystem and Fisheries*, eds G. Duhamel, and D. Welsford, (Paris: Société française d'ichtyologie), 233–255.

Constable, A. J., Melbourne-Thomas, J., Corney, S. P., Arrigo, K. R., Barbraud, C., Barnes, D. K., et al. (2014). Climate change and southern ocean ecosystems i: how changes in physical habitats directly affect marine biota. *Glob. Chang. Biol.* 20, 3004–3025. doi: 10.1111/gcb.12623

Costello, C., Gaines, S. D., and Lynham, J. (2008). Can catch shares prevent fisheries collapse? *Science* 321, 1678–1681. doi: 10.1126/science.1159478

Costello, C., Lynham, J., Lester, S. E., and Gaines, S. D. (2010). Economic incentives and global fisheries sustainability. *Ann. Rev. Res. Econom.* 2, 299–318. doi: 10.1146/annurev.resource.012809.103923

Cox, M. (2014). Understanding large social-ecological systems: introducing the SESMAD project. *Int. J. Commons* 8, 265–276.

Cox, M., Arnold, G., and Tomas, V. (2010). A review of design principles for community-based natural resource management. *Ecol. Soc.* 15:38.

Cristofari, R., Liu, X., Bonadonna, F., Cherel, Y., Pistorius, P., Le Maho, Y., et al. (2018). Climate-driven range shifts of the king penguin in a fragmented ecosystem. *Nat. Clim. Change* 8, 245–251. doi: 10.1038/s41558-018-0084-82

Croxall, J. P. (2008). The role of science and advocacy in the conservation of southern ocean albatrosses at sea. *Bird Conserv. Int.* 18, s13–s29. doi: 10.1017/s0959270908000300

Davies, T. E., Epstein, G., Aguilera, S. E., Brooks, C. M., Cox, M., Evans, L. S., et al. (2018). Assessing trade-offs in large marine protected areas. *PLoS One* 13:e0195760. doi: 10.1371/journal.pone.0195760

Downes, M., and Downes, E. (2006). "Sealing at heard island in the nineteenth century," in *Heard Island: Southern Ocean Sentinel*, eds K. Green, and E. J. Woehler (Chipping Norton, NSW: Surrey Beatty & Sons Pty Limited), 184–195.

Downes, M. C., Ealey, E. H. M., Gwynn, A. M., and Young, P. S. (1959). The birds of heard island. *ANARE Rep.* 1:135.

Duhamel, G., and Welsford, D. (2011). *The Kerguelen Plateau: Marine Ecosystems and Fisheries*. Paris: Société française d'ichtyologie.

Einoder, L. D. (2009). A review of the use of seabirds as indicators in fisheries and ecosystem management. *Fisher. Res.* 95, 6–13. doi: 10.1016/j.fishres.2008.09.024

Fisheries, A. (2018). *Austral Fisheries Awards and Achievements*. Available: https://www.australfisheries.com.au/about-us/awards (accessed March 20, 2019).

Fleischman, F. D., Ban, N. C., Evans, L. S., Epstein, G., Garcia-Lopez, G., and Villamayor-Tomas, S. (2014). Governing large-scale social-ecological systems: lessons from five cases. *Int. J. Commons* 8, 428–456.

Freer, J. J., Tarling, G. A., Collins, M. A., Partridge, J. C., and Genner, M. J. (2019). Predicting future distributions of lanternfish, a significant ecological resources within the southern ocean. *Biodivers. Res.* 25, 1259–1272.

Goldsworthy, L., Zuur, B., and Llewellyn, G. (2016). "Marine protected areas in the antarctic and sub-antarctic region," in *Big, Bold and Blue: Lessons From Australia's Marine Protected Areas*, eds G. Wescott, and J. Fitzsimmons, (Clayton, MO: CSIRO Publishing), 99–116.

Goverment of Australia, (1953). *Heard Island and McDonald Islands Act 1953*. Canberra, ACT: Goverment of Australia.

Goverment of Australia, (1979). *"Commonwealth of Australia Gazette, No. S189" (26 September 1979)*. Canberra, ACT: Australian Goverment Publications Service.

Goverment of Australia, (1981). *"Antarctic Marine Living Resources Conservation Act 1981." Act No. 30 of 1981*. Canberra, ACT: Goverment of Australia.

Goverment of Australia, (1991). *Fisheries Management Act 1991 No. 162 of 1991*. Canberra, ACT: Goverment of Australia.

Goverment of Australia, (1994). *Maritime Legislation Amendment Act 1994 No. 20*. Canberra, ACT: Goverment of Australia.

Goverment of Australia, (1996). *"National Strategy for the Conservation of Australia's Biological Diversity", Department of the Environment, Sport and Territories*. Canberra, ACT: Goverment of Australia.

Goverment of Australia, (1998). *Australia's Oceans Policy - Specific Sectoral Measures*. Canberra, ACT: Environment Australia.

Goverment of Australia. (1999). *Environment Protection and Biodveristy Conservation Act*. Canberra, ACT: Goverment of Australia.

Goverment of Australia, (2002). *Heard Island and McDonald Islands Marine Reserve Proposal*. Canberra, ACT: Environment Australia.

Goverment of Australia, (2005). *Heard Island and McDonald Islands Marine Reserve Management Plan*. Canberra, ACT: Australian Antarctic Division and Director of National Parks.

Grafton, R. Q., Arnason, R., Bjørndal, T., Campbell, D., Campbell, H. F., Clark, C. W., et al. (2006). Incentive-based approaches to sustainable fisheries. *Can. J. Fisher. Aquatic Sci.* 63, 699–710. doi: 10.1139/f05-247

Green, K. (2006). "Sovereignty, science and twentieth century sealing," in *Heard Island: Southern Ocean Sentinel*, eds K. Green, and E. J. Woehler, (Chipping Norton, NSW: Surrey Beatty & Sons), 196–201.

Green, K., and Woehler, E. J. (2006). *Heard Island: Southern Ocean Sentinel*. Chipping Norton, NSW: Surrey Beatty & Sons.

Gruby, R. L., Gray, N. J., Campbell, L. M., and Acton, L. (2016). Toward a social science research agenda for large marine protected areas. *Conserv. Lett.* 9, 153–163. doi: 10.1111/conl.12194

Heritage Expeditions (2012). *Species List From Voyage 1262: South Indian Ocean to Heard and McDonald Islands*, 16.

Heritage Expeditions (2018). *Heard Island*. Available: https://www.heritage-expeditions.com/destination/heard-island/ (accessed March 14, 2019).

IUCN. (2017). *IUCN World Heritage Outlook: Heard and McDonald Islands*. Available: https://www.worldheritageoutlook.iucn.org/explore-sites/wdpaid/145576 (accessed 20 March 2019).

Jones, P. J. S., and De Santo, E. M. (2016). Viewpoint – is the race for remote, very large marine protected areas (VLMPAs) taking us down the wrong track? *Mar. Policy* 73, 231–234. doi: 10.1016/j.marpol.2016.08.015

McKinlay, J. P., Welsford, D., Constable, A., and Nowara, G. B. (2008). An assessment of the exploratory fishery for dissostichus spp. on BANZARE Bank (CCAMLR Division 58.4.3b) based on fine-scale catch and effort data. *CCAMLR Sci.* 15, 55–78.

Meyer, L., Constable, A., and Williams, R. (2000). *Conservation of Marine Habitats in the Region of Heard Island and McDonald Islands*. Fountain Valley, CA: Kingston Technology.

Mitchell, W., and Schmeider, R. (2017). *Retreat of Stephenson Glacier, Heard Island, from Remote Sensing and Field Operations*. San Francisco, CA.

Moore, G. J., Wienecke, B., and Robertson, G. (1999). Seasonal change in foraging areas and dive depths of breeding king penguins at heard island. *Polar Biol.* 21, 376–384. doi: 10.1007/s003000050376

MSC, (2018). *Australian Heard Island and McDonald Islands Toothfish & Icefish fisheries. Marine Stewardship Council*. Available: https://fisheries.msc.org/en/fisheries/australian-heard-island-and-mcdonald-islands-toothfish-icefish-fisheries/ (accessed March 18, 2019).

Muir, A. K. M. (2010). Illegal, unreported and unregulated fishing in the circumpolar arctic. *Arctic Inst. North Am.* 63, 373–378.

Munro, G. (2006). "Waiting on the weather" - the ANARE years 1947-1955," in *Heard Island: Southern Ocean Sentinel*, eds K. Green, and E. J. Woehler (Chipping Norton, NSW: Surrey Beatty & Sons), 202–230.

Olson, M. (1965). *The Logic of Collective Action*. Cambridge, MA: Harvard University Press.

Österblom, H., and Bodin, O. (2012). Global cooperation among diverse organizations to reduce illegal fishing in the southern ocean. *Conserv. Biol.* 26, 638–648. doi: 10.1111/j.1523-1739.2012.01850.x

Österblom, H., and Sumaila, U. R. (2011). Toothfish crises, actor diversity and the emergence of compliance mechanisms in the southern ocean. *Glob. Environ. Change* 21, 972–982. doi: 10.1016/j.gloenvcha.2011.04.013

Ostrom, E. (1990). *Governing the Commons*. Cambridge: Cambridge University Press.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science* 325, 419–422. doi: 10.1126/science.1172133

Ostrom, E., Gardnder, R., and Walker, J. M. (1994). *Rules, Games, and Common-Pool Resources*. Ann Arbor, MI: University of Michigan Press.

Parsons, M., Mitchell, I., Butler, A., Ratcliffe, N., Frederiksen, M., Foster, S., et al. (2008). Seabirds as indicators of the marine environment. *ICES J. Mar. Sci.* 65, 1520–1526. doi: 10.1093/icesjms/fsn155

Patterson, H., and Skirtun, M. (2012). "Heard Island and McDonald Islands Fishery," in Fishery Status Reports 2012. Canberra, ACT: ABARES.

Peron, C., Weimerskirch, H., and Bost, C. A. (2012). Projected poleward shift of king penguins' (Aptenodytes patagonicus) foraging range at the crozet islands, southern indian ocean. *Proc. Biol. Sci.* 279, 2515–2523. doi: 10.1098/rspb.2011.2705

Péron, C., Welsford, D. C., Ziegler, P., Lamb, T. D., Gasco, N., Chazeau, C., et al. (2016). Modelling spatial distribution of Patagonian toothfish through life-stages and sex and its implications for the fishery on the Kerguelen Plateau. *Prog. Oceanogr.* 141, 81–95. doi: 10.1016/j.pocean.2015.12.003

Phillips, R. A., Gales, R., Baker, G. B., Double, M. C., Favero, M., Quintana, F., et al. (2016). The conservation status and priorities for albatrosses and large petrels. *Biol. Conserv.* 201, 169–183. doi: 10.1016/j.biocon.2016.06.017

Potts, T., and Haward, M. (2006). International trade, eco-labelling, and sustainable fisheries – recent issues, concepts and practices. *Environ. Dev. Sustainabil.* 9, 91–106. doi: 10.1007/s10668-005-9006-9003

Putz, K., Ropert-Coudert, Y., Charrassin, J.-B., and Wilson, R. (1999). Foraging areas of king penguins aptenodytes patagonicus breeding at possession island, southern indian ocean. *Mar. Orinthol.* 27, 77–84.

Reid, K. (2019). "Commission for the conservation of antarctic marine living resources (CCAMLR): implementation of conservation of southern ocean marine living resources," in *Governing Marine Living Resources in the Polar Regions*, eds N. Liu, C. M. Brooks, and T. Qin, (Cheltenham: Edward Elgar Publishing).

Saldaña, J. (2015). *The Coding Manual for Qualitative Researchers*. Thousand Oaks, CA: SAGE.

Smith, A. D. M., Sainsbury, K. J., and Stevens, R. A. (1999). Implementing effective fisheries-management systems – management strategy evaluation and the Australian partnership approach. *ICES J. Mar. Sci.* 56, 967–979. doi: 10.1006/jmsc.1999.0540

Stokstad, E. (2010). Behind the eco-label, a debate over antarctic toothfish. *Science* 329, 1596–1597. doi: 10.1126/science.329.5999.1596

Stoll-Kleemann, S., and O'Riordan, T. (2011). From participation to partnership in biodiversity protection: experience from germany and south africa. *Soc. Nat. Res.* 15, 161–177. doi: 10.1080/089419202753403337

Tickler, D., Meeuwig, J. J., Palomares, M.-L., Pauly, D., and Zeller, D. (2018). Far from home: distance patterns of global fishing fleets. *Sci. Adv.* 4:eaar3279. doi: 10.1126/sciadv.aar3279

Trathan, P. N., and Agnew, D. (2010). Climate change and the antarctic marine ecosystem: an essay on management implications. *Antarctic Sci.* 22, 387–398. doi: 10.1017/s0954102010000222

UNESCO, (1997). *Report of the Twenty-First Session of the World Heritage Committee*. Naples: UNESCO.

Watson, R. A., Nowara, G. B., Hartmann, K., Green, B. S., Tracey, S. R., and Carter, C. G. (2015). Marine foods sourced from farther as their use of global ocean primary production increases. *Nat. Commun.* 6:7365. doi: 10.1038/ncomms8365

Weimerskirch, H., and Robertson, G. (1994). Satellite tracking of light-mantled sooty albatrosses. *Polar Biol.* 14, 123–126.

Welsford, D. (2011). Evaluating the impact of multi-year research catch limits on overfished toothfish populations. *CCAMLR Sci.* 18, 47–55.

Welsford, D., Candy, S. G., Verdouw, J. J., and Hutchins, J. J. (2012). *Robust characterisation of the age structure, Growth and Recruitment of Toothfish in the Macquarie Island and Heard Island and McDonald Islands fisheries*. Kingston, TAS: Australian Antarctic Division

Welsford, D., Constable, A., and Nowara, G. B. (2011). "The Heard Island and McDonald Islands Marine Reserve and Conservation Zone - A model for Southern Ocean marine reserves?," in *The Kerguelen Plateau: Marine Ecosystems And Fisheries*, eds G. Duhamel, and D. Welsford, (Paris: Société française d'ichtyologie), 297–304.

Welsford, D., Ewing, G. P., Constable, A., Hibberd, T., and Kilpatrick, R. (2014). *Demersal Fishing Interactions with Marine Benthos in the Australian EEZ of the Southern Ocean: An Assessment of the Vulnerability of Benthic Habitats to Impact by Demersal*. Kingston, TAS: The Department of the Environment, Australian Antarctic Division and the Fisheries Research and Development Corporation

Welsford, D. C., Dell, J., and Duhamel, G. (2019). The kerguelen plateau. in *Proceedings of theMarine Ecosystems and Fishereis. Proceedings of the Second Symposium*. Kingston, TAS

WG-FSA. (2017). *Report of the Working Group on Fish Stock Assessment*. Hobart, TAS: Working Group on Fish Stock Assessment.

Whinam, J., and Shaw, J. D. (2018). *"Australia's World Heritage Islands," in Australian Island Arks: Conservation, Management and Opportunities*. Clayton, MI: CSIRO Publishing.

Wiedenfeld, D. A. (2016). *Seabird Bycatch Solutions for Fishery Sustainability*. Plains, VA: American Bird Conservancy.

Wilhelm, T. A., Sheppard, C. R. C., Sheppard, A. L. S., Gaymer, C. F., Parks, J., Wagner, D., et al. (2014). Large marine protected areas - advantages and challenges of going big. *Aqua. Conserv.* 24, 24–30. doi: 10.1002/aqc.2499

Williams, R., Tuck, G. N., Constable, A., and Lamb, T. (2002). Movement, growth and available abundance to the fishery of dissostichus eleginoides Smitt, 1898 at heard island, derived from tagging experiments. *CCAMLR Sci.* 9, 33–48.

Woehler, E. J. (2006). "Status and conservation of the seabirds of heard island," in *Heard Island: Southern Ocean Sentinel*, eds K. Green, and E. J. Woehler, (Chipping Norton, NSW: Surrey Beatty & Sons), 12–165.

Yin, R. K. (2014). *Case Study Research*. Los Angeles, CA: Sage.

Ziegler, P., and Welsford, D. (2019). "The patagonian toothfish (dissostichus eleginoides) fishery at heard islan an mcdonald islands (HIMI) – population structure an history of the fishery stock assessment," in *The Kerguelen Plateau: Marine Ecosystems and Fisheries*, eds D. Welsford, J. Dell, and G. Duhamel, (Kingston, TAS: Australian Antarctic Division), 187–217.

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