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Marine spatial planning for the conservation of albatrosses and large petrels breeding at South Georgia

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ABSTRACT

Tracking of seabirds at sea is valuable for marine spatial planning. Many seabirds are of conservation concern, including albatrosses and large petrels (Procellariiformes) which face a major threat from mortality in fisheries. We examine how important areas used by seven of these species breeding at South Georgia change throughout the year, based on tracking data collected between 1991 and 2012, and discuss the implications for spatial management in the region within the current jurisdictional framework.

Foraging areas overlapped with a patchwork of national and international management organizations, and areas outside clear jurisdiction. National waters were generally unimportant, besides that of South Georgia. The other exception was Falkland Islands coastal waters, which were important for wandering albatrosses *Diomedea exulans* during incubation, and were opened for new oil and gas drilling in 2015. The marine protected area established at the South Orkney Islands protects very little habitat used by the tracked seabirds; however, a northern extension of this would benefit a number of species at different breeding stages.

The area around South Georgia was important year-round, including in periods when fishing is allowed. A contiguous region to the north of this was also important and here, mechanisms should be improved to ensure compliance with bird bycatch mitigation recommendations. The study highlighted the use of tracking for identifying key areas for pelagic albatrosses and petrels, and the advantages of incorporating these data into a multilateral approach to marine spatial planning to ensure the future conservation of these highly-threatened marine predators.

1. Introduction

The loss of terrestrial biodiversity and habitat can be ameliorated, to some extent, by establishing national parks (Rodrigues et al., 2004; Le Saout et al., 2013). The creation of such national parks has a long history, with the first designated at Yellowstone, USA in 1872, yet similar protection measures were only implemented in the marine realm much more recently. Targets initially set at the World Summit on Sustainable Development in 2002, aiming to reduce biodiversity loss by establishing a network of MPAs by 2012, were not met and were revised in 2010 to a more achievable goal of protecting 10% of ecological systems in the marine and coastal environment by 2020, known as Aichi Target 11. The aim is to establish a network of MPAs that are "ecologically representative and well-connected" and "integrated into the wider land- and seascape" by 2015. Though these redefined targets are more qualitative, meeting them remains a major challenge; to date, MPAs have been designated in just 2.8% of the global ocean (International Union for the Conservation of Nature and United Nations Enivironment Programme-World Conservation Monitoring Centre, 2013).

The existing MPAs are mainly located within 200 M of the coast, under national jurisdictions or EEZs. The notion of national EEZs was developed by the United Nations and implemented under the 1982 UNCLOS in order to help resolve territorial disputes over ocean resource ownership and exploitation. Management of areas within EEZs is simplified, in theory, because they are controlled by a single organization; a national government. UNCLOS categorized areas beyond these zones as "the common heritage of mankind", which amounts to more than two thirds of the surface of the global ocean (and 70% of its volume) and is classified as "high-seas" (Rogers et al., 2014). The high seas comprise 45% of the earth's surface and yet only 0.79% of their area is designated as MPAs (High Seas Alliance, 2014). Although out of sight of most of the human population, and seemingly far removed from coastal fisheries within EEZs that are more heavily legislated, increasing recognition of the intrinsic value provided by the high seas has led to calls for the establishment of high seas MPAs (Game et al., 2009). In terms of commercial fishing, Rogers et al. (2014) showed that 99% of commercial fish species span both coastal and high seas habitats. Recent modeling of the link between commercial fisheries within EEZs and

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Table 1
Number of tracks included in study in each year, species and breeding stage. As these species breed in the austral summer (with egg laying in Sept. to Dec.) the year indicated is the year in which the chicks fledge.

Species, IUCN Red List Status and Population Trend	Stage	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Wandering Albatross Vulnerable / Decreasing	Incubation															17								
	Brood		14	14						22		14			30	22								
	Post-brood		30							22	22	30		54		31		14			31			
Black-browed Albatross Threatened / Decreasing	Incubation							14					22											
	Brood													19								67		
	Post-brood				54									23										
Grey-headed Albatross Endangered / Decreasing	Incubation													23										
	Brood					8																30		30
	Post-brood				57	19		16				11										33		33
Light-mantled Sooty Albatross Near-threatened / Decreasing	Incubation																							
	Brood																							
	Post-brood														42									
White-chinned Petrel Vulnerable / Decreasing	Incubation														14									
	Brood																							
	Post-brood									22														
Northern Giant Petrel Least concern / Increasing	Incubation																							
	Brood																30							
	Post-brood																							
Southern Giant Petrel Least concern / Increasing	Incubation																24							
	Brood																13							
	Post-brood																13							

those in the high seas illustrated that complete closure of the high seas to all fishing would lead not only to a dramatic recovery of global fish stocks, but also to increased profitability of fisheries within EEZs (White and Costello, 2014).

Despite the importance of the offshore marine environment, UNCLOS is not set up as a global instrument for the designation of MPAs in the high seas, neither does it stipulate the requirement for Environmental Impact Assessments of activities in the high seas, and nor is there any other appropriate legal framework in existence that does so (Scott, 2012). New regulatory frameworks have been called for, as has the use of surveillance technology for their enforcement (Delfour-Samama and Leboeuf, 2014). Currently, the majority of high seas fishery management is carried out by an incomplete patchwork of regional fisheries management organizations. In some cases, these are directed at a single species, or a small group of related species, and national membership is voluntary with resolutions optional, even for signatories (Small, 2005). Implementation of their regulations is variable, depending on licensing controls and resources available for policing and enforcement; indeed, current levels of observer coverage are considered far below that sufficient to estimate seabird bycatch accurately (Churchill, 2011; Phillips, 2013). More than two thirds of fisheries managed by RFMOs lack regional observer coverage, and fish stocks in waters with no national jurisdiction have been shown to be systematically over exploited (McWhinnie, 2009; Gilman et al., 2014).

The geopolitical landscape in the region used by albatrosses and petrels breeding at South Georgia is diplomatically complex and to a large extent reflects the challenges facing high seas protection in general, having no clear global structure or framework for management of threatening processes other than fishing and pollution (Kimball, 2005). The first MPA to be established in the high seas was implemented under CCAMLR in 2009; the South Orkney Islands Southern Shelf MPA. In October 2014, the fourth round of talks at CCAMLR aimed at moving forward with the designation of further MPAs in the Southern Ocean collapsed when consensus could not be reached. High seas management has been identified as one of the most important issues for the conservation of global biodiversity (Sutherland et al., 2009). New structures for high seas governance under the United Nations Convention on the Law of the Sea (UNCLOS) have been debated since the United Nations Conference on Sustainable Development recognized the need for high seas biodiversity conservation in 2012 (Ban et al., 2014). However, implementation of new instruments for cohesive management of the global ocean is not imminent and it is not clear how current geopolitical concerns can be surmounted in the immediate future.

The distributions of seabirds are recognized as important indicators of marine ecosystem processes (for example, the black-browed albatross *Thalassarche melanophris* is used as an ecosystem monitoring indicator species by the CCAMLR and can therefore inform the process of MPA design (De Monte et al., 2012; Wong et al., 2014). When used in this way, seabird distribution acts as a proxy for ecosystem productivity; the MPAs that have been designated on this basis within EEZs provide some benefits to the indicator species if they encompass near-shore foraging or rafting zones (Tanner et al., 2008). However, many seabirds forage predominantly in the high seas where protection measures are varied and fragmented. Not only do the lack of cohesive governance, geopolitical issues and competition with fisheries for natural resources make high seas protection difficult, but also seabirds are more threatened, and their conservation status poorer, than any other comparable bird group, with commercial fishing and pollution constituting the main threats while at sea (Croxall et al., 2012). Fishing vessels have been shown to be important foraging cues for seabirds and, each year, an estimated 200,000 and 400,000 seabirds, respectively, are killed in longline, and gillnet fisheries, and mortality is of a similar order in trawl fisheries (Anderson et al., 2011; Løkkeborg, 2011; Žydelis et al., 2013).

Here, we compile available tracking data collected during the breeding season from seven species of medium-sized to large Procellariiformes (albatrosses and petrels) at South Georgia (wandering albatrosses *Diomedea exulans*, black-browed albatrosses, gray-headed albatrosses *Thalassarche chrysostoma*, light-mantled albatrosses *Phoebetria palpebrata*, white-chinned petrels *Procellaria aequinoctialis*, northern giant petrels *Macronectes halli* and southern giant petrels *Macronectes giganteus*). We examine the regulatory frameworks in force across the distribution of these seven species, review the conservation measures that have been put in place by the different management organizations, the extent of observer coverage and the degree of compliance, to assess the degree of protection afforded in different parts of the range to each species, and how this changes throughout the year.

2. Methods

Wandering, black-browed, gray-headed and light-mantled albatrosses and white-chinned, northern giant and southern giant petrels breeding at South Georgia (54°00′S, 38°03′W) were tracked during incubation, brood-guard (early chick-rearing) and post-brood (mid to late chick rearing) in one or more seasons from 1991 to 2012.

Availability of data varied in terms of species, breeding stage, number of years, and sample size, and deployments were of satellite transmitters PTTs or GPS loggers, providing a total of 1222 tracks (Table 1). Years in which fewer than eight tracks were available for a species during a breeding stage were disregarded since fewer than this number is considered insufficient to determine important areas reliably (Soanes et al., 2013). The mean interval between locations for tracks recorded by PTT was 81 min (max. 195 min), and by GPS was 21 min (max. 23 min). All tracks were interpolated to give one location per hour using the R package "trip" and filtered by speed to remove locations

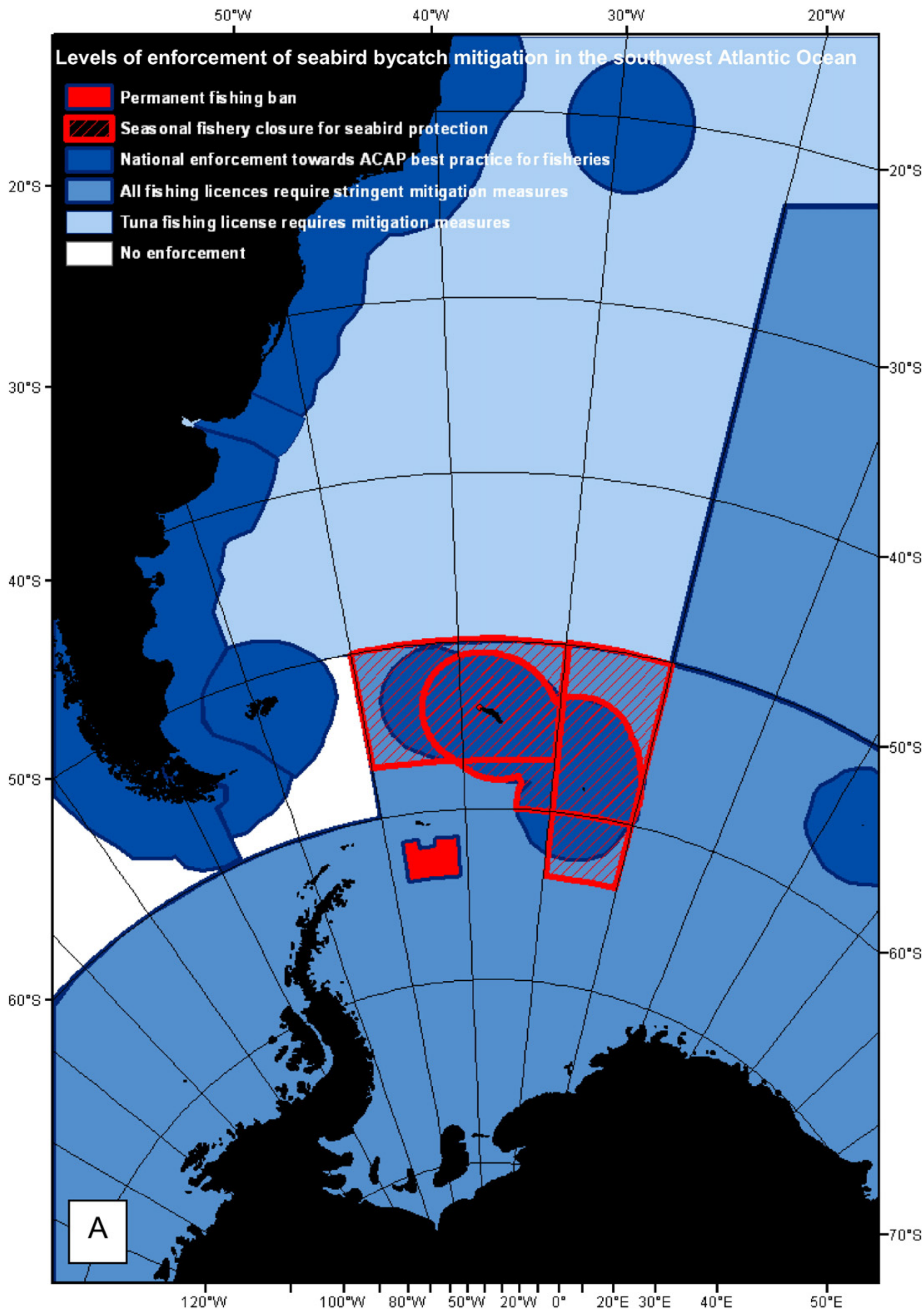


Fig. 1. A—Levels of bycatch mitigation enforcement: 1. Permanent fishing ban; 2. Seasonal fishery closure (for timings see Figure S2); 3. National jurisdiction; 4. All fishing controlled by license; 5. Tuna fishing controlled by license; 6. No protection. B—National maritime jurisdictions C—Marine protected areas D—Regional marine management organizations South East Atlantic Fisheries Organisation (SEAFO), Argentine-Uruguayan Common Fishing Zone (ZCPAU), Permanent Commission for the South Pacific (CPPS), International Commission for the Conservation of Atlantic Tunas (ICCAT), Commission for the Conservation of Southern Bluefin Tuna (CCSBT), Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) E—Ecologically important areas (IBAs (Lascelles, Taylor et al. 2016), ACAP region represents global albatross and petrel distribution) in the space used by breeding wandering, black-browed, gray-headed and light-mantled albatrosses and white-chinned, northern giant and southern giant petrels tracked at South Georgia between 1991 and 2012.

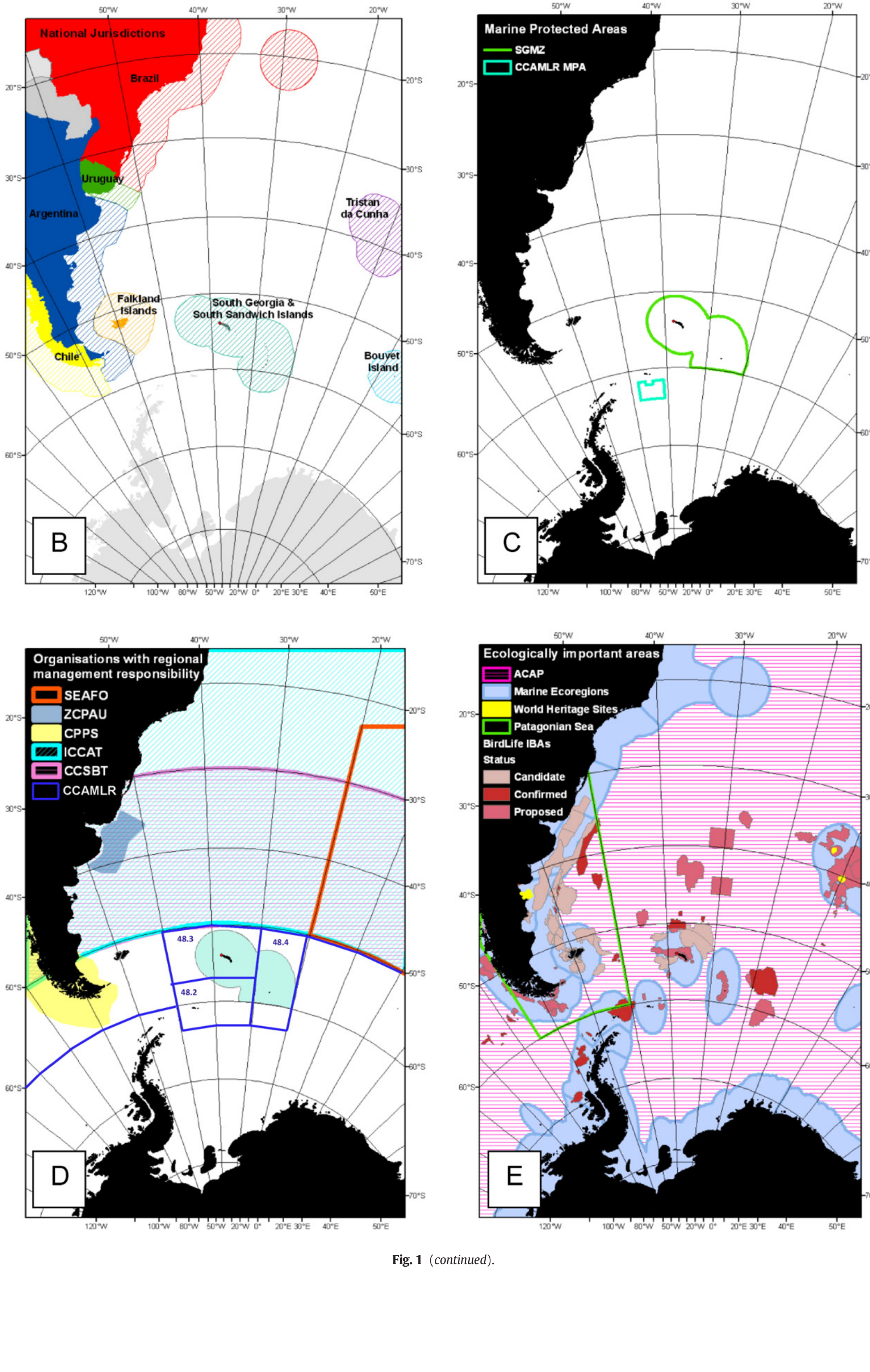


Fig. 1 (*continued*).

generated by ground speeds exceeding the maximum usually observed (McConnell et al., 1992; Wakefield et al., 2009).

Recent studies have concluded that kernel analysis is appropriate for the identification of important areas for flying seabirds (Tancell et al., 2012; Delord et al., 2014). Kernel rasters of seabird distribution were calculated from the tracking data using the GME package of R scripts based on a quartic approximation to the bivariate normal distribution with a bandwidth (or smoothing factor h) of 10 km so that the quartic

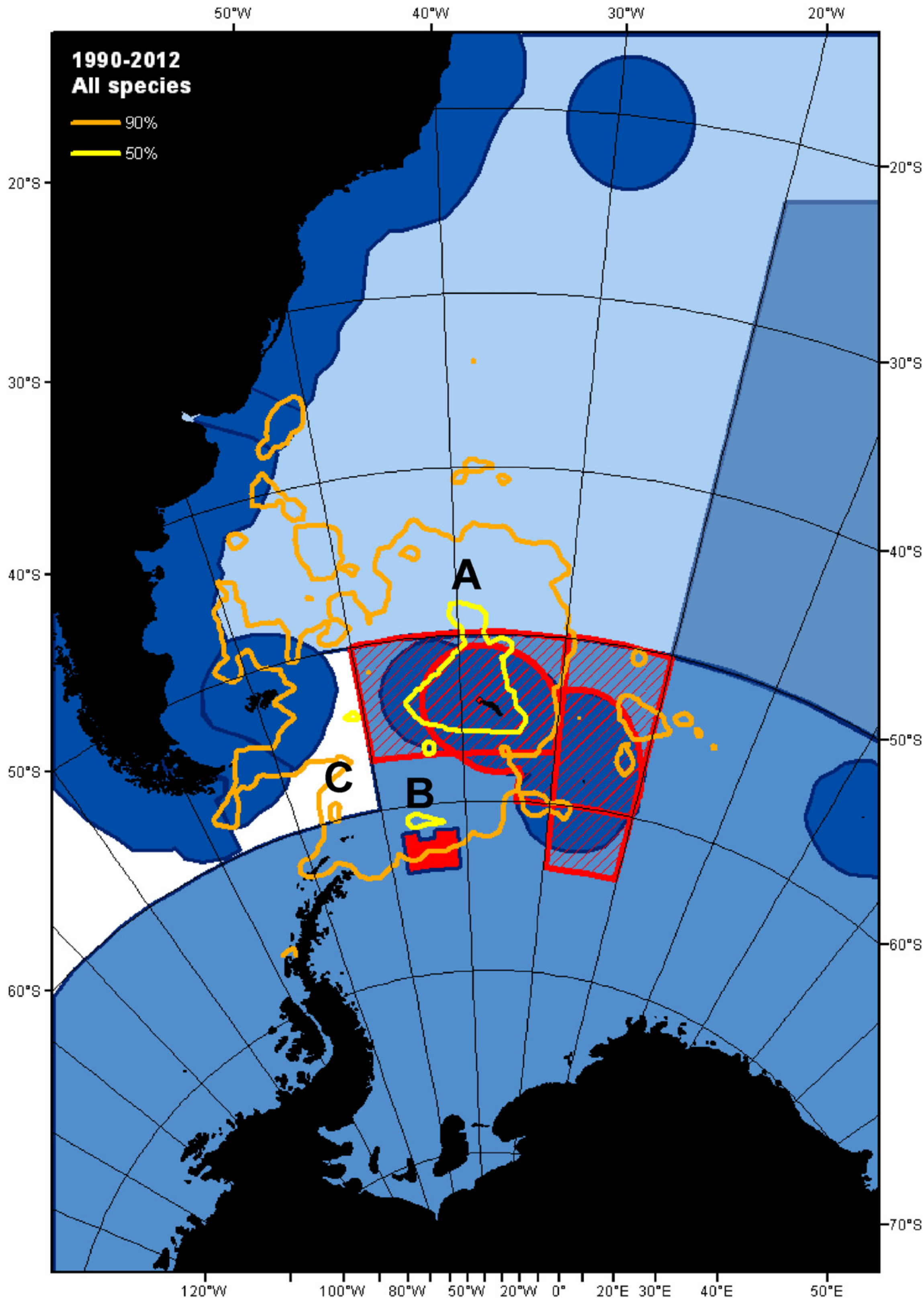


Fig. 2. 90 and 50 PVCs for seven species of seabird breeding at South Georgia between 1991 and 2012 overlaid on map of levels of seabird by-catch mitigation enforcement.

kernel bandwidth parameters correspond to a real distance on the ground (as opposed to the bivariate normal kernel with parameters corresponding to a covariance matrix). Kernel rasters were generated on a grid of fixed extent and a cell size of 100 km (comparable with scales at which the relevant marine management bodies operate) and calculated for each species, year and breeding stage. The resulting rasters were assumed to represent the distribution of the species for the duration of a given breeding stage (Fig. S1).

The combined distribution of breeding birds of all seven species throughout the calendar year was determined by summing rasters generated for each species and breeding stage (using ArcGIS python scripts) to produce a single composite year-round raster. Temporal variation was incorporated by weighting the distribution for each species and breeding stage in each calendar month according to the proportion of that month during which the birds were in each breeding stage (Fig. S1). Single rasters, thus weighted, were generated for each calendar month. Contours showing regions of the kernel density surface which included 50% (50PVC) and 90% (90PVC) of the kernel density were calculated using the GME. These contours were assumed to be the upper and lower limits of the kernel density surface considered to be useful for the identification of important areas from tracking data (Borger et al., 2006). They were not assumed to represent any particular aspect of bird behavior, although some studies have used the 50PVC as an indication of the extent of the core foraging area (Bogdanova et al., 2014).

The degree of protection afforded to albatrosses and large petrels from the most serious threat, incidental mortality in fisheries, varies according to the legislative powers and capacity for enforcement of the range of bodies responsible for bycatch mitigation. Each portion of the distribution of these seabirds was ranked according to the level of management legislation intended to reduce bird bycatch. This is not necessarily an indication of the effectiveness of each management regime, but rather represents the degree of potential legislative or regulatory power. The national priority of parties to the ACAP, was assumed to be the enforcement of mitigation measures on all fishing vessels in order to achieve ACAP best practice, although in practical terms, this intent may be compromised by logistical and economic constraints. The EEZ of South Georgia is managed under the auspices of CCAMLR, with particular provisions applying to the SGMZ, which was declared an MPA in 2012 (Trathan et al., 2014). For this reason, the South Georgia EEZ is usually referred to in terms of the relevant management regimes (SGMZ or CCAMLR). Hence, the level of bycatch prevention in different sectors of the southwest Atlantic was considered to be as follows, in descending order: permanent fishing ban; seasonal fishery closure aimed at seabird protection; national jurisdiction; fishery management organization control requiring all licensed vessels fishing for any species within the geographical purview to use mitigation measures defined by that organization; tuna (and tuna-like species) fishery management organization control requiring vessels targeting only those species to carry out mitigation measures defined by that organization; no enforcement (Fig. 1, A).

3. Results

3.1. Management regime

The spatial distribution of wandering albatrosses, black-browed albatrosses, gray-headed albatrosses, light-mantled albatrosses, white-chinned petrels, northern giant petrels and southern giant petrels from South Georgia during the breeding season overlapped with a patchwork of marine management jurisdictions and various areas identified as important for the conservation of seabirds and other marine taxa (Fig. 3, B). These included the national EEZs of Brazil, Uruguay, Argentina, Chile, Bouvet Island (Norway), and the Falkland Islands, Tristan da Cunha, South Georgia and the South Sandwich Islands (all UK); two MPAs (the SGMZ and the CCAMLR MPA to the south of the South Orkney Islands), and; the area of operation of the following living resource or fisheries management organizations, the ICCAT, SEAFO, CCSBT, ZCPAU, CPPS and CCAMLR (Fig. 1, D). It also included areas of internationally recognized ecological importance including World Heritage Sites, the Patagonian Sea Ecosystem, BirdLife Important Bird Areas (Lascelles et al., 2016) and a number of the Marine Ecoregions defined by Spalding et al. (2007) although none of these areas confer protection via legislative control.

3.2. Year-round seabird distribution

Eighty-six percent of the area used most intensively by tracked birds (the 50PVC) was inside the region subject to seasonal fishery closures under the auspices of CCAMLR, making this the most important management organization for the albatrosses and large petrels breeding at South Georgia (Fig. 2 and Table 2). The organization with jurisdiction over the second largest fraction of the area of highest use (10% of the 50PVC) was ICCAT. None of the 50PVC fell within the most highly protected area – the CCAMLR MPA to the south of the South Orkney Islands – although there was an area of high use by the tracked birds that was directly to the north of the existing MPA (Fig. 2, Region B). Four percent of the 50PVC fell in the region afforded no protection (Fig. 2, Region C).

Management of areas used less intensively by seabirds (represented by the 90PVC) was controlled by CCAMLR, ICCAT and the national EEZs of Argentina, Brazil, Uruguay, Chile, the Falkland Islands, and South Georgia and the South Sandwich Islands. CCAMLR was the most important organization with management responsibility in this region, with jurisdiction over 47% of the area of the 90PVC (Fig. 2 and Table 2). Only 31% of the 90PVC fell within the CCAMLR subarea 48.3 (afforded the second highest level of protection against seabird bycatch) and 15% fell within CCAMLR areas not subject to seasonal fishery closures (Fig. 2 and Table 2). Only 1% of the 90PVC fell within the existing CCAMLR MPA. Thirteen percent of the 90PVC fell within national EEZs outside the CCAMLR area (assumed to afford the same levels of protection) with the Falkland Islands responsible for the largest share, followed by Argentina, Uruguay and Chile (Fig. 2 and Table 2). The greatest overlap of the 90PVC with a national EEZ was with that of South Georgia and the South Sandwich Islands. Seven percent of the area of the 90PVC fell within areas afforded no statutory protection. In general, across the 90PVC, management regimes varied greatly in the protection afforded to seabirds.

Table 2
Summary of important areas with resource management regimes.

Organization with management responsibility		Percentage of 50PVC of year-round distribution	Percentage of 90PVC falling within area of jurisdiction
CCAMLR		86	47
of which:	CCAMLR subarea 48.3(including national waters of South Georgia and the South Sandwich Islands)		31
	CCAMLR areas not subject to seasonal fishery closures	10	15
	CCAMLR marine protected area		1
ICCAT		10	33
National waters (other than SGSSI)			13
Falkland Islands			8
Argentina			3
Uruguay			2
Chile			<1
No statutory protection		4	7

3.3. Seasonal variation

Fisheries managed by CCAMLR and in the SGMZ are subject to seasonal closures aimed at preserving fish stocks and reducing interactions between seabirds and fishing vessels (Fig. S2). The degree of overlap between these seasonal fisheries and areas of high use by seabirds varied throughout the year (Fig. 3, Panels A to I). Important areas remained the same from June to September, since this period coincides only with the post-brood stage for the wandering albatross; the other six seabirds in our study breed during the austral summer. The most important organization for management of the high seas for the seven study species, in every calendar month, was CCAMLR (Fig. 4). For example, during February, the whole of the 50PVC for all seven species fell within the area managed by CCAMLR, when wandering albatrosses were incubating, and the other six study species were rearing chicks. The percentage of the 50PVC falling within the CCAMLR area reached a minimum of 60% between June and November. During this period, the proportion of the 50PVC falling within the areas managed by ICCAT and within national EEZs reached maxima of approximately 35% and 10%, respectively.

3.4. Species- and stage-specific variation

The importance of the management organizations operating in the study area varied widely according to the species and the breeding stage (Fig. S3). None of the areas of highest use for any species at any breeding stage fell within the existing South Orkneys MPA (Fig. S3). Seasonal fisheries closures aimed at seabird conservation coincided effectively with the breeding season of most species during most breeding stages. During the incubation period of the wandering albatross, both the krill fishery in the SGMZ and the longline fishery in CCAMLR subarea 48.3 are closed in order to protect breeding seabirds (Fig. S2). During this stage, 62% of the area of highest use by wandering albatrosses was in waters closed to fishing, with the remainder almost equally in the Falkland Islands EEZ, and outside any management jurisdiction (Fig. S3, A). Approximately 1% was within each of the EEZs of Argentina and Chile. During the brood stage, the area of highest use by wandering albatrosses was entirely within the region subject to two fishery closures (Fig. S3, B). In contrast, these fisheries were open during the post-brood period, i.e., the majority of chick-rearing of wandering albatrosses, and more than half of the area of greatest use by this species fell within this region (Fig. S3, A and C).

During incubation, the majority of the area of highest use by black-browed albatrosses overlapped with the area managed by ICCAT, with the remainder in CCAMLR waters (Fig. S3, D). During the brood stage, all of the area of highest use was within CCAMLR waters and so was subject to fishery closures; however, during both incubation and post-brood stages, a proportion of the area of highest use fell within this region but not subject to fishery closures (Fig. S3, E and F). Incubating gray-headed albatrosses were afforded the least protection of any species and stage under current management regimes, with only 11% of the area of highest use subject to seasonal fishery closures and 20% overlapping with the region without any current management jurisdiction (Fig. S3, G). It is unclear if fishing activity occurs in this region, since there is no mandatory requirement for reporting to a single authority.

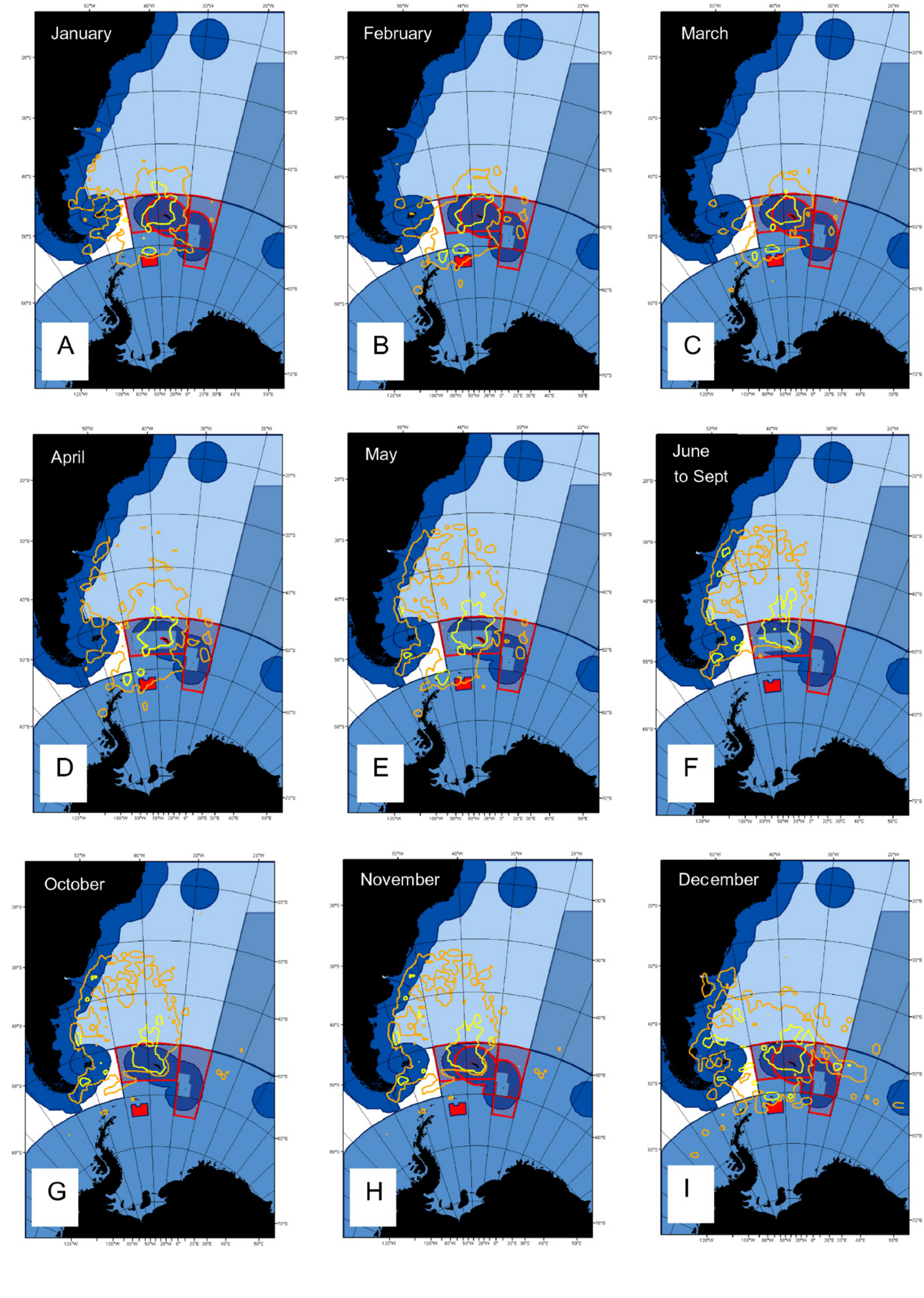
During the post-brood stage (the only breeding stage during which this species were tracked), 61% of the area of highest use by light-mantled albatross overlapped with the area of the CCAMLR/SGMZ fishery closures, with the remainder either under CCAMLR control or in the region with no management authority (Fig. S3, J). During the post-brood stage for white-chinned petrels (the only stage for this species included in the study), 96% of the area of highest use was subject to CCAMLR or SGMZ fishery closures, with the remainder under CCAMLR control (Fig. S3, K). Areas of highest use for northern giant petrels fell entirely within the regions subject to seasonal fishery closures except during the post-brood stage, when 18% of the high use area fell within the area managed by CCAMLR, approximately 100 km north of the existing CCAMLR MPA (Fig. S3, L, M and N). The majority of the areas of highest use at all breeding stages for southern giant petrels fell within the area subject to seasonal fishery closures. During the post-brood stage, the area falling outside this region was at a maximum, with 34% in CCAMLR waters (Fig. S3, O, P and Q).

4. Discussion

4.1. Year-round distribution in relation to management

Eighty-six percent of the area used most intensely (represented by the 50PVC) year-round by wandering, black-browed, gray-headed and light-mantled albatrosses, and white-chinned, northern giant and southern giant petrels breeding at South Georgia fell within the region currently managed by the Commission for the Conservation of Antarctic Marine Living Resources. Within these waters, seabirds are afforded protection from the risk of incidental mortality by seasonal closure of two of the three fisheries (aimed at conserving both fish stocks and seabirds), and for the rest of the year by the stringent bird bycatch mitigation measures required of all licensed fishing vessels (Fig. S2). In addition, the likelihood of encountering IUU fishing is reduced greatly because of regular patrols by a dedicated vessel around South Georgia on the shelf break, the core fishing ground for Patagonian Toothfish *Dissostichus eleginoides*. Twenty-nine nations (and, by default, all EU countries) are signatories to CCAMLR and the organization is recognized as an exemplar of ecosystem-based fisheries management (Kock, 2001; Bodin and Österblom, 2013). This level of protection is second only to a complete fishing ban, and indeed in practical terms is usually preferable as policing of fishing prohibitions requires very large expenditure on patrol vessels to prevent illegal, unreported and unregulated fishing, and can displace vessels with poor practices and no bird bycatch observer scheme into adjacent waters. In areas where fishing is allowed and in the absence of a coordinated legal framework for the implementation and management of high seas marine protection, such as that proposed by Scott (2012), the CCAMLR region is afforded the greatest protection under the available management frameworks. Although CCAMLR's ability to administer MPAs effectively while balancing the increasing demands of the lucrative fishing industry has recently been called into question (Cullis-Suzuki and Pauly, 2010; Brooks, 2013), at present there seems no reason to doubt its commitment to minimizing seabird bycatch.

The area of intense use by the tracked albatrosses and petrels extended beyond the boundary of the CCAMLR area into a contiguous region comprising 8% of the 50PVC, in which licenses for tuna and tuna-like species are controlled by the International Commission for the Conservation of Atlantic Tuna. Although licensed vessels registered to the fifty-three ICCAT signatory nations must in theory adhere to strict seabird bycatch mitigation measures, the level of observer coverage of most fleets represents approximately 5% of fishing effort; hence there is limited information on compliance and bycatch levels remain high, particularly in the northwest of the study region off Uruguay and Brazil (Phillips, 2013; Yeh et al., 2013). The seabird bycatch mitigation measures required by ICCAT are similar to those suggested by ACAP as best practice and enforced in the CCAMLR area, but the persistent high bycatch rates by some fleets operating in the ICCAT area, and the low level of observer coverage and monitoring of compliance, lowers its protection category below that of CCAMLR (Fig. 1, A). The ICCAT quota system is aimed at fish stock management, and there are no seasonal closures that might benefit seabirds if these were timed to coincide with periods in which there would otherwise be high overlap between birds and vessels. ICCAT and CCAMLR have different aims and membership, within a complex network of interrelated bodies, and pelagic longline fisheries within the ICCAT area catch substantial numbers of seabirds, with those breeding at South Georgia amongst the most seriously impacted (Tuck et al., 2011; Jiménez et al., 2012; Jiménez et al., 2014).


January
A
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December
I

None of the areas of greatest use by the tracked seabirds from South Georgia overlapped with the South Orkney Islands MPA (Figs. 2, 3 and S3) where a complete fishing ban is imposed by CCAMLR, although there was an area of high use directly to its north (Fig. 2, Region B). A very small proportion of the area of greatest use (0.9%; c. 100 km^2) by the tracked albatrosses and petrels was in the region with no fishery or conservation management and it is unclear how much fishing occurs here since there are no licensing or reporting obligations (Fig. 2, Region C). In summary, the areas of most intense use, year-round, by seabirds breeding at South Georgia are in regions managed by CCAMLR and ICCAT.

The outer limit of the area identified as important for the tracked seabirds (90PVC) overlapped with the Exclusive Economic Zones of six territories, Brazil, Uruguay, Argentina, Chile, SGSSI, and the Falkland Islands, as well as areas managed by CCAMLR and ICCAT (Figs. 1 and 3). Each of these territories has a NPOA for the protection of seabirds and is a signatory, or in the cases of the two UK Overseas Territories, the sovereign state is a signatory, to the Agreement on the Conservation of Albatrosses and Petrels. The NPOAs encourage, but do not always mandate, the use of best-practice bycatch mitigation recommended by ACAP, and the capacity for implementation and enforcement inevitably depends on available resources and national priorities (ACAP, 2014). The area of overlap between the 90PVC and national EEZs was greatest for SGSSI, which falls entirely within the CCAMLR area, followed by the Falkland Islands, Argentina, Uruguay and Brazil (Fig. 2). Seven percent of the 90PVC fell in areas with no legislative protection.

The area of the 90PVC is large, spanning a patchwork of management regimes described above. Even if protection of this entire area were feasible, the efficacy of very large marine protected areas has been questioned (Singleton and Roberts, 2014). Less intensely used areas may be important to only a small proportion of individuals and prey resources in those regions may not be predictable or exploited every year (Piatt et al., 2006; Miller and Christodoulou, 2014). Moreover, their use may fluctuate seasonally, becoming more important in some months. Nevertheless, the birds from South Georgia may be acting as indicator species, as the regions identified in this study may be used by birds breeding at other locations or by non-breeding birds, as on the Patagonian Shelf (Croxall and Wood, 2002; Falabella et al., 2009; Global Ocean Commission, 2014). Moreover, although major advances have been made in recent years towards the prevention of seabird deaths via interaction with fisheries within the area managed by CCAMLR, and to some extent also in longline fisheries within the EEZs of Brazil and Uruguay (Jiménez and Domingo, 2007; Bugoni et al., 2008), breeding populations of Wandering, Black-browed and Gray-headed Albatrosses and White-chinned Petrels at South Georgia are still in decline and it may be that the source of the residual unmitigated bycatch occurs within these areas of less intense use (Tuck et al., 2011).

4.2. Seasonal and species-specific variation in areas of high use

CCAMLR was consistently the management organization with responsibility for the largest portion of the area of greatest use by the tracked seabirds in this study, in every month (Fig. 4). Since CCAMLR is held up as an exemplar of ecosystem-based management and a leader in the implementation and enforcement of bycatch mitigation, this is reassuring. The entire region of highest use at all breeding stages for northern and southern giant petrels fell under CCAMLR control, as did that of brooding wandering albatrosses, both brooding and post-brood black-browed albatrosses and post-brood white-chinned petrels (the only stage in which this species was tracked) (Fig. S3). However, the strict geographic limits of CCAMLR's influence mean that when the area of highest use by seabirds extends beyond those boundaries, their conservation depends on other management bodies with differing priorities and remits (Grant, 2005). For example, between May and September, an increasing proportion of the contiguous area of highest use overlapped with waters within the jurisdiction of ICCAT (Fig. 4), where black-browed and wandering albatrosses, and southern giant petrels are amongst seabirds most commonly reported as bycatch, including by the Taiwanese, Brazilian and Uruguayan fleets (Bugoni et al., 2008; Jiménez et al., 2010; Yeh et al., 2013).

The area in which tuna fisheries is managed by ICCAT overlapped with areas of high use for post-brood wandering albatrosses, incubating black-browed albatrosses, and gray-headed albatrosses at all breeding stages but particularly incubation. These represent different times of year, however, which would make it difficult for ICCAT to focus monitoring or management in particular months (Fig. S3). Areas of high use by black-browed albatrosses did not overlap with those of any other species, whereas there was a high degree of spatial overlap between the distributions of post-brood wandering albatrosses, and gray-headed albatrosses at all breeding stages. This overlap zone is adjacent to CCAMLR waters and could be a useful focus of future collaboration between CCAMLR and ICCAT (Fig. 2, Region A). Although CCAMLR has established a coherent network of terrestrial ASPAs and ASMAs south of 60°S, little progress has been made in the designation of MPAs in CCAMLR waters since the South Orkneys MPA was established in 2009. Yet, there is clearly a need for conservation to work across geopolitical boundaries to establish MPAs if Aichi Target 11 is to be achieved, and the southwest Atlantic is one region where there is justification for coordinated efforts such as those described by Kimball (2005). Although there has been a push for improved collaboration between CCAMLR, ICCAT and ACAP, the identification of an area of high use for formal protection, or improved uptake of mitigation with comprehensive observer coverage to ensure bycatch monitoring and compliance could potentially serve as a useful model for a wider seabird protection framework.

4.3. Conservation management by CCAMLR

The fishery for Patagonian Toothfish in CCAMLR subarea 48.3 (Fig. S2) is open from mid-April to August, and is closed at other times in order to avoid the main seabird breeding season (Parkes, 2000; Waugh et al., 2008). The krill fishery within the SGMZ is closed over a similar period (Fig. S2). During these months, the distribution of seabirds breeding at South Georgia extends much further north than the demarcated grounds of either fishery (Fig. 3). However, it is evident that these seven species of seabird tend to be much more widely dispersed in the northern portion of their distribution (the 90PCV) and the core area of greatest importance (50PVC) remains mainly in CCAMLR waters (Fig. 4). The portion of the 50PVC falling within CCAMLR subarea 48.3 remains relatively stable throughout the year (Fig. 3, D, E and F). Although the species composition changes (with the migration elsewhere of the summer-breeding species), CCAMLR subarea 48.3 remains very important for wandering albatrosses, which are rearing chicks during the months when the fishery is open. This species forages across a much broader area during this period than at other breeding stages. Nevertheless, more than half of the area of greatest use for this species falls within this region, and consequently, interaction with vessels is potentially very high; as such, it is imperative that the vessel operators and observers ensure strict adherence to bycatch mitigation practices to safeguard this vulnerable species.

Fig. 3. Panels A to I: Monthly variations in important areas for seven seabird species breeding at South Georgia between 1991 and 2012. Background shows temporal changes in levels of protection against mortality through fishery by-catch. Orange line represents 90PVC, yellow line represents 50PVC.

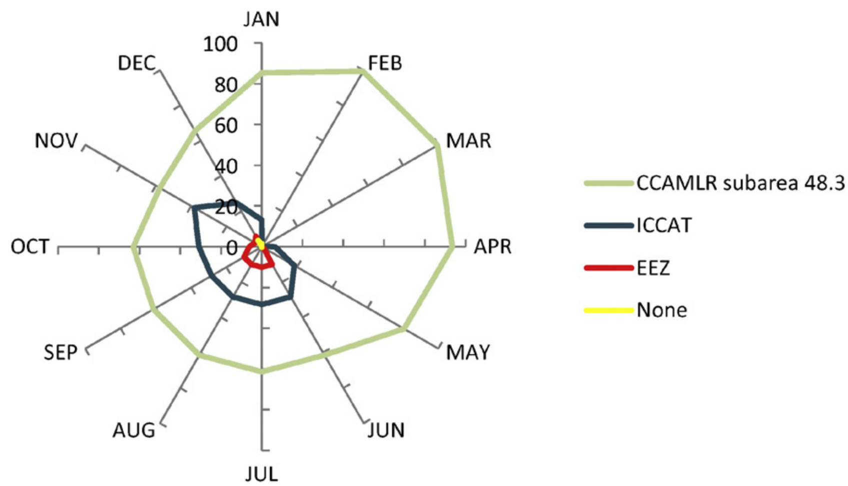

Fig. 4. Percentage of the most intensely used area by all species (50PVC) falling under the protection of the Commission for the Conservation of Marine Living Resources CCAMLR, the International Commission for the Conservation of Atlantic Tuna ICCAT, National Exclusive Economic Zones EEZ and areas with no management or protection. Summed proportions for each organization represent 100% of the 50PVC in each month.

4.4. Conservation management in EEZs

Between May and December, the distribution of the tracked seabirds became more fragmented, with the 90PVC (i.e. the area of least intense use beyond the extent of the 50PVC) and a minority of the areas of greatest use (50PVC) extending into the EEZs of Uruguay, Argentina, Chile and the Falkland Islands, mainly reflecting the foraging areas of wandering albatrosses in chick-rearing and, from September onwards, the summer breeders during incubation (Fig. 3). Black-browed albatrosses and white-chinned petrels have been reported as the most common bycatch species in the Brazilian fishery in November, and wandering albatrosses in the Uruguayan pelagic longline fishery between May and November (Bugoni et al., 2008; Jiménez et al., 2014. White-chinned petrels from South Georgia spend the non-breeding period on the Patagonian Shelf and off coastal Chile, a minority of black-browed albatrosses from South Georgia and the entire population from the Falklands, and, for part of the non-breeding season, also gray-headed albatrosses from South Georgia, use Patagonian Shelf waters (Croxall et al., 2005; Phillips et al., 2005; 2006; Wakefield et al., 2011). This underlines the importance of coordinated effort to ensure national fisheries bodies implement effective bird bycatch mitigation practices in the Patagonian Shelf region, which would particularly benefit those breeding at South Georgia during the last year quarter (also see Jiménez et al., 2014). If funds for observer programs are limited, prioritization of coverage to that period could maximize conservation benefits. For example, from January to April, the most important areas for seabirds from South Georgia outside CCAMLR waters did not overlap with EEZs of South American countries (Fig. 3). Fisheries within these EEZs are active during this time but not visited by seabirds from elsewhere. A study of the Argentine fishery for kingclip *Genypterus blacodes* conducted from January to March, found low seabird bycatch rates although this could be for reasons other than low seabird abundance (Seco Pon et al., 2007). This seasonal variation in the importance of national EEZs for seabirds could be mirrored by temporally-nuanced conservation effort in revisions of the relevant NPOAs.

Exploratory oil drilling was scheduled to begin in the Falkland Islands EEZ in 2015 (Stanley, 2014). Oil drilling poses threats to seabirds that are attracted by lights at night, flaring and discarded food, and bird deaths have been observed around offshore platforms in the north-west Atlantic due to collisions with rig structures, oiling and burning in the rig flares (Wiese et al., 2001). From June to September, areas of highest use by wandering albatrosses (the only species breeding during this period) overlapped with the Falkland Islands EEZ. Indeed, this was the only species in which areas of highest use overlapped with any EEZ outside the SGMZ (Fig. S3). The planned period for oil drilling is between March and August, which includes the end of the incubation period when use of the Falkland Islands EEZ by wandering albatrosses peaks (Fig. S3). A recent Environmental Impact Assessment by Falkland Oil and Gas Limited (an oil and gas exploration company with extensive licenses in the Falklands EEZ) does not acknowledge this overlap (Falkland Oil and Gas Limited, 2012). The Falkland Islands has separate seabird NPOAs for longline and trawl fisheries. These focus on the protection of seabirds that breed in the Falkland Islands, but acknowledge that future priorities include the protection of visiting birds from other colonies and the identification of important areas at sea (Janzen et al., 2011).

4.5. Management of the South Orkney Islands marine protected area

The MPA on the southern shelf of the South Orkney Islands was designated partly to protect important predator foraging areas (Commission for the Conservation of Marine Living Resources, 2009). From the perspective of the albatrosses and large petrels breeding at South Georgia, this MPA conveys negligible advantage. Overlap between the area of low intensity use by these species (the region between the 50PVC and 90PVC) and the MPA is, at best, marginal (Figs. 2, 3 and S3). The area of greatest use by seabirds (50PVC) did not overlap with the MPA; neither was there any overlap with areas of greatest use (50PVCs) of individual species (Fig. S3). However, from December to April (when all seven study species are breeding), the area around the South Orkney Islands and to the north of the existing MPA are amongst those used most intensely by the tracked birds (Fig. 3). Areas of high use were close to the existing MPA (Fig. 2, Region B) for incubating and brooding black-browed albatrosses and post-brood gray-headed albatrosses, light-mantled albatrosses, northern giant petrels and southern giant petrels. An extension of the existing MPA to include this area would be beneficial to these species in particular. However, establishing such an extension would be challenging as it requires agreement by all CCAMLR signatories and progress within CCAMLR over MPA designations in general has been fraught with difficulty in recent years (Brooks, 2013). Indeed, there are few precedents for successfully extending an existing MPA in other regions (Grant, 2005; Hooker et al., 2011).

4.6. Areas beyond current jurisdictions

The areas of highest use by incubating wandering and gray-headed albatrosses, and post-brood light-mantled albatrosses included regions currently under no management framework, where fishing activity is therefore unmonitored, unreported and unregulated (Fig. 2, Region C). The Magnuson Stevens Reauthorization Act, in force in the United States, states that the definition of illegal, unreported or unregulated fishing should include a range of fishing activities “located beyond national jurisdiction, for which there are no applicable conservation or management measures or in areas with no applicable international fishery management organization or agreement” (US Government, 2006). Lack of suitable frameworks for enforcement of such intentions makes them difficult to implement but the sentiment may usefully inform necessary action wherever gaps in management occur, as they do here.

Most of the study species do not breed in significant numbers elsewhere in the South Atlantic. However, inclusion of data from black-browed albatrosses and southern giant petrels at the Falklands, Chilean island groups or Patagonia may have identified other important areas on the Patagonian Shelf but is unlikely to have affected the areas identified in this study. Non-breeding birds, being free from central-place foraging constraints and largely subject to different winter prey distributions, abundances and availability, are likely to exhibit very different distributions and habitat preferences. It is therefore not feasible to infer coincidence of important areas between breeding and non-breeding birds.

In summary, the areas of the marine environment important to the seven species of seabird tracked in this study fall within a complex and incomplete patchwork of management and protection provided by organizations with different aims. These include international treaties (CCAMLR, ACAP), regional fisheries management organizations (ICCAT) and national jurisdictions as well as areas of interest to Non-Governmental Organisations (BirdLife IBAs). Of these, only nations which have, by default, jurisdiction over their 200 M marine exclusive economic zones, can impose any conservation measures by statute. Those organizations that award fishing licenses (under an international treaty system, or through targeted species management) are able to address seabird deaths through interaction with fishing vessels but have a limited mandate to minimize other threats, for example from pollution, marine development or habitat loss. Areas identified as important ecologically for particular species, can serve to inform decision-making by those bodies with legislative or licensing powers but the designating bodies (e.g. BirdLife International) lack the authority to stipulate or enforce conservation measures.

Engagement between conservation bodies and fishery management organizations has reduced seabird deaths caused by fishing (Small, 2005). However, by definition, fisheries management organizations represent commercial interests and their geographical remit is incomplete. The patchwork nature of these and other management regimes in this region adds to the difficulty of the already complex steps necessary to move from important area identification to practical implementation (Dunn et al., 2014). This regional study underlines calls for new high-seas management structures to much more effectively ensure the protection of wide-ranging seabirds and other taxa (Scott, 2012; Delfour-Samama and Leboeuf, 2014; Global Ocean Commission, 2014). Until such structures are in place, the process of establishing an effective global network of marine protected areas in the high seas remains a major challenge.

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Appendix A. Supplementary data

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