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At sea movement of Macquarie Island giant petrels: Relationships with marine protected areas and Regional Fisheries Management Organisations

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ABSTRACT

Satellite tracking devices were used to examine the at sea movements of southern and northern giant petrels from Macquarie Island during the Austral summers of 2005–06 and 2006–07. Time spent at sea for nine northern giant petrels (four breeding adults, five recently fledged juveniles) and 10 southern giant petrels (three breeding adults, one non-breeding adult, and six recently fledged juveniles) was examined in relation to marine protected areas and fishing activity in the area immediately adjacent to Macquarie Island in 2005–06, and in terms of the jurisdictions of Regional Fisheries Management Authorities (RFMOs) at a broader scale during both seasons. Breeding adult southern and northern giant petrels spent a large proportion of their time at sea in the Macquarie Island Marine Park (25% and 65%, respectively), primarily during chick rearing. Further from Macquarie Island, the most important foraging areas for adult giant petrels were the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) statistical sub-areas 58.4.1 and 88.1, where foraging activity was concentrated around the ice edge and the Polar Frontal Zone. Fledglings of both species spent time in the Marine Park immediately after fledging, before moving into international waters. We found significant temporal and spatial overlap in the areas used by recently fledged juvenile northern giant petrels and the areas utilised by the single trawler that operated in these waters during 2005–06. Adult giant petrels spent little time in RFMO waters other than those under the jurisdiction of CCAMLR, but fledgling southern and northern giant petrels spent considerable time (56% and 78% of total time at sea) on the high seas of the Pacific Ocean, in areas under the jurisdictions of the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the Western and Central Pacific Fisheries Commission (WCPFC), the Inter American Tropical Tuna Commission (IATTC) and the South Pacific Regional Fisheries Management Organisation (SPRFMO). Band returns indicate that the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the South East Atlantic Fisheries Organisation (SEAFO) areas are likely to be extensively utilised by Macquarie Island giant petrels in the first three years after fledging. Overall, Macquarie Island's giant petrel populations are well protected by marine reserves during the breeding season. However, after fledging birds move into

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RFMO areas that currently have low standards of observer coverage and by catch mitigation, and where fisheries related mortality is likely to pose a significant risk.

1. Introduction

Ongoing consideration of seabird distribution in relation to fisheries activities is fundamental to the maintenance of effective management regimes designed to mitigate seabird by catch. Such assessments are now routinely carried out in some major fisheries management regimes (SC-CCAMLR XXIII, 2004) and presentation of fine scale information on seabird foraging activities forms a critical part of this process. RFMOs have a central role to play in the conservation of albatross and petrel species, as they are responsible for the management of a number of the fisheries that are known or likely to be killing substantial numbers of albatrosses and petrels each year. While the level of protection for seabirds offered by RFMOs is variable, parties to RFMOs nonetheless have an obligation to implement management measures that minimise impacts on seabirds (Food and Agriculture Organisation of the United Nations, 1999). Knowledge of the at sea distribution of seabirds will therefore be an important component of developing management strategies for RFMOs in the Southern Ocean.

The management and conservation of highly mobile and migratory marine predators such as seabirds is one of the greatest challenges faced by marine ecosystem managers (Lopez-Mendilaharsu et al., 2005). Habitats used by such species may be relatively discrete, at least seasonally, and suitable as candidates for conservation (Zacharias and Roff, 2001). While marine protected areas (MPAs) can be effective in the protection of top-order predators (Hooker and Gerber, 2004), there is often a paucity of data that can be used in evaluating their efficacy in achieving this purpose (Terauds et al., 2006). Because of the vast areas covered by migrating marine predators, management standards imposed by international agreements and Regional Fisheries Management Organisations (RFMOs) will also be central in determining the anthropogenic risks encountered on the high seas (Croxall and Nicol, 2004). Understanding the habitat use of such far-ranging predators is crucial to assessing whether MPAs can be useful tools in species conservation and management (Hyrenbach et al., 2000; Boersma et al., 2002; Field et al., 2004; Hooker and Gerber, 2004; Lopez-Mendilaharsu et al., 2005; Hyrenbach et al., 2006) and in assessing the level of protection offered by international agreements and RFMOs.

Macquarie Island (Fig. 1), a small and isolated subantarctic island 1500 km south of Australia, is an important breeding site for both southern and northern giant petrels (*Macronectes giganteus* and *M. halli*), with annual breeding populations of approximately 2100–2300 pairs and 1400 pairs, respectively (Johnstone, 1977; DPIW, 2006). While the precise worldwide populations of both species are unknown, it is clear that the Macquarie Island populations account for significant proportions of the worldwide populations of both species (10–19% for southern giant petrels and 3–9% for northern giant petrels (BirdLife International, 2005). Both giant petrel species are known to be killed during fishing operations in the Southern Ocean (Brothers et al., 1999). To date, there has been no tracking based investigation of the Macquarie Island populations of either species and there is therefore very little information regarding their distributions away from the island, how these distributions relate to MPAs, and the extent of overlap with fishing activities.

Macquarie Island is adjacent to a network of MPAs that may afford varying levels of benefit and significance for the seabird species breeding there (Terauds et al., 2006). These MPAs include Australia's 200 nm economic exclusion zone (EEZ), the Macquarie Island Marine Park, and the waters surrounding the Antarctic continent under the competence of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) (see Section 2). The Macquarie Island Marine Park was established expressly to protect top-order predators, including giant petrels (Environment Australia, 2001). The remaining waters in this sector of the Southern Ocean are administered by other Regional Fisheries Management Organisations. Birdlife International (2005) identified the International Commission for the Conservation of Atlantic Tuna (ICCAT), CCAMLR and the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) as being the most important RFMOs in terms of overlap with giant petrel distributions.

Both northern and southern giant petrels have been observed foraging in waters close to Macquarie Island during both the breeding and non-breeding periods (Australian Fisheries Management Authority (AFMA) observers, unpublished; Weinecke and Roberston, 2002), however, foraging distributions have not previously been examined. This study quantifies the areas used by adult giant petrels during incubation (southern giant petrels only) and chick rearing (southern giant petrels and northern giant petrels) and by newly fledged juveniles (both species). We determine the amount of time spent by these birds in MPAs and RFMOs, and the potential for interaction with fisheries operations. The zoning of the Macquarie Island Marine Park includes a multiple use category that permits a commercial Patagonian toothfish trawl fishery. We examine the overlap between giant petrel foraging areas and the spatial distribution of fishing effort in this fishery because it is within close proximity to the breeding grounds, reflecting concern that fishing activity within 200 nm of the island poses a very high risk to both breeding birds and recently fledged juveniles. We also analyse the geographical distribution of band returns from 1996 until present to augment information gained from the satellite tracking, and to infer use of RFMO areas other than those where birds were satellite tracked in the current treatment. Band return data prior to 1996 are not considered in the current treatment,

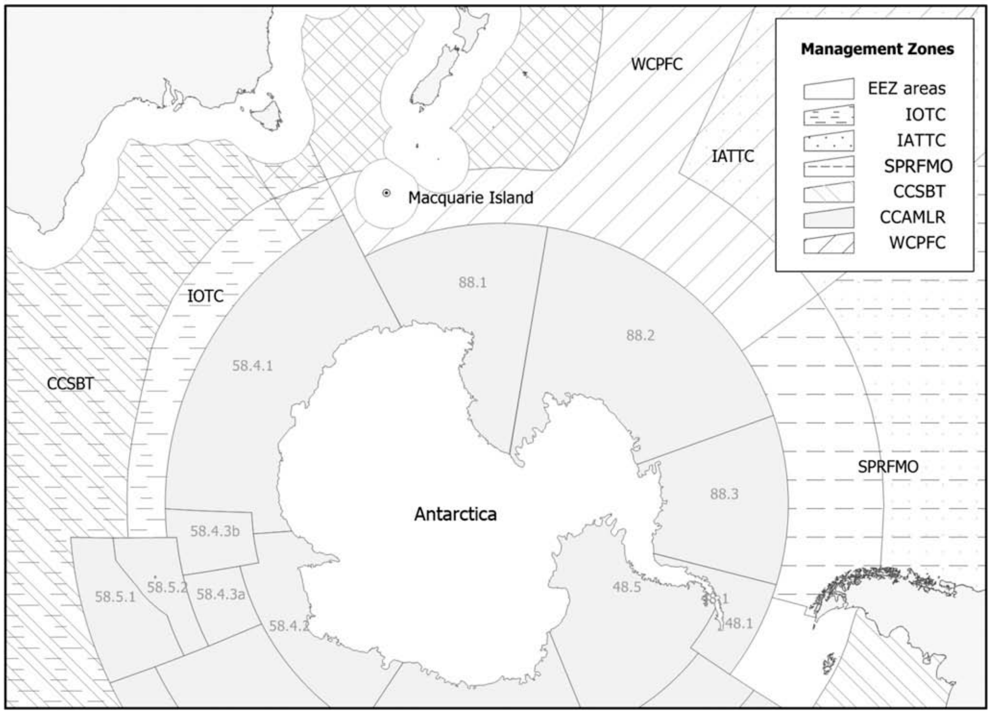

Fig. 1 – Location of Macquarie Island in relation to the Australian EEZ, New Zealand EEZ, CCAMLR statistical sub-areas and other major RFMOs within the foraging range of giant petrels from Macquarie Island.

as they have been examined elsewhere (Woehler and Johnstone, 1988; Patterson and Hunter, 2000).

2. Methods

2.1. *Study site and species*

Macquarie Island (54° 30′ S, 158° 55′ E) is a small, isolated subantarctic island, situated approximately 1500 km south of Australia (Fig. 1). It is a nature reserve (including surrounding waters to 3 nm from the coast), an International Biosphere Reserve, and a World Heritage Area (including waters to 12 nm from the coast).

Macquarie Island's northern giant petrels lay eggs from late September to mid-October. Chicks hatch at the end of November, and fledge in mid-February. The timing of breeding for southern giant petrels is generally four to six weeks later than for northern giant petrels, with laying taking place in November, hatching in mid-January and fledging in late-March (Warham, 1962; Johnstone, 1971; Woehler and Johnstone, 1988).

2.2. *Management zones*

2.2.1. *Australian exclusive economic zone (EEZ) and embedded management zones*

A 200 nm Australian EEZ surrounds Australia, including Macquarie Island (Fig. 1). The Macquarie Island Australian EEZ possesses the characteristics of an IUCN category IV or VI Protected Area (Anon, 1994) by virtue of strict conservation measures prescribed by the Australian Government to minimise the impact of longline fishing practices on seabirds (Department of Environment and Heritage, 2006). The waters within 3 nm of the Coast of Macquarie Island are managed by the Tasmanian State Government and no fishing is permitted within this zone. Also embedded within the Macquarie Island Australian EEZ is the Macquarie Island Marine Park (Environment Australia, 2001), an MPA of approximately 16 million hectares (Fig. 2). The Marine Park is divided into a central highly protected zone (HPZ, assigned to IUCN category Ia) and two habitat/species management zones (HSMZ, IUCN category IV) either side of the HPZ. The HPZ was specifically established to protect threatened species and migratory and foraging animals from direct human disturbance; accordingly commercial or recreational fishing, mining operations and commercial tourism activities are all prohibited in this zone. The management goals for the HSMZs permit commercial fishing. A single trawl vessel has fished in these waters in most years since 1996 under a fishing licence that imposes strict environmental conditions (AFMA, 2003). In addition, limited commercial tourism and scientific research that is compatible with the strategic objectives of the Marine Park are also allowed in the HSMZs (Environment Australia, 2001).

2.2.2. *Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)*

CCAMLR came into force in 1982. The agreement forms part of the Antarctic Treaty System. The area of application of the Convention includes the waters of the Southern Ocean that extend south of an approximation of the northern extent of the Antarctic Convergence (varies from latitude 45–60° S). CCAMLR waters possess the characteristics of an IUCN

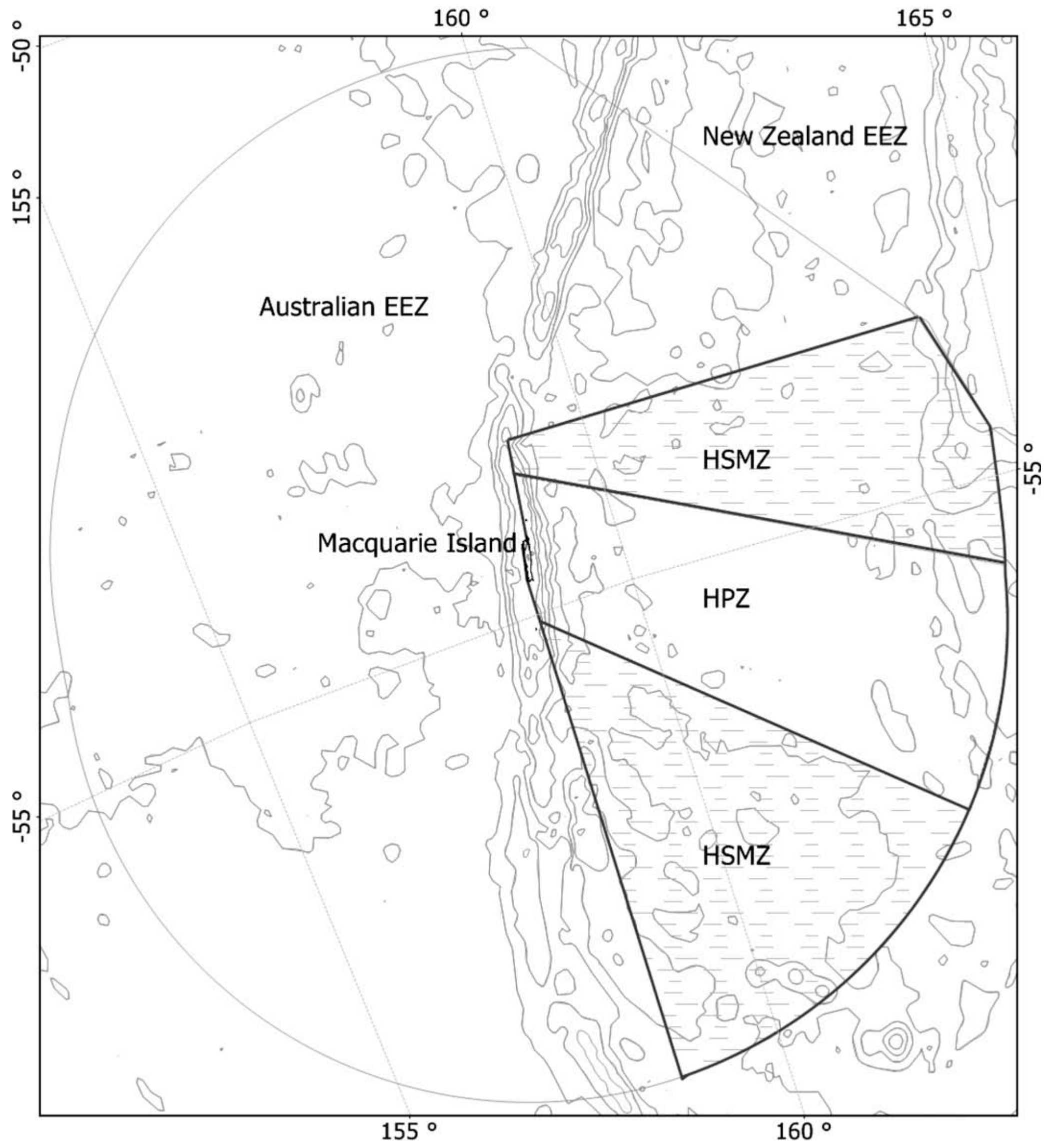

Fig. 2 – Macquarie Island Marine Park showing habitat/species management zones (HSMZ) and the highly protected zone (HPZ). Contours show 1000 m isobaths.

Category IV or VI protected area because the Convention has established formal measures to mitigate the incidental mortality of seabirds from fishing (Terauds et al., 2006). These measures have virtually eliminated by catch of albatrosses and petrels in regulated longline fisheries in the convention area (SC-CCAMLR XXIII, 2004). As such, we consider CCAMLR as a marine protected area, rather than a typical RFMO, for the purposes of this investigation.

2.2.3. *Regional Fisheries Management Organisations*

The Food and Agriculture Organisation of the United Nations (FAO) define RFMOs as 'intergovernmental fisheries organisations or arrangements, as appropriate, which have the competence to establish fishery conservation and management measures'. The majority of the "high seas" in the southern hemisphere fall under the competence of RFMOs. In addition to CCAMLR, these currently include: (1) CCSBT; (2) the Western and Central Pacific Fisheries Commission (WCPFC); (3) the Indian Ocean Tuna Commission (IOTC); (4) ICCAT; and (5) the South East Atlantic Fisheries Organisation (SEAFO) (Figs. 1 and 5). In addition, the Galapagos Agreement, not yet in force, plans to establish a new RFMO in the Southeast Pacific (South Pacific RFMO or SPRFMO), and the Permanent Commission for the South Pacific is acting as Secretariat in the interim period (BirdLife International, 2005). Small (2005) examined the by catch reduction performance of RFMOs, defining their overall performance in terms of five key elements: (1) mandates that include non-target species; (2) commitment to minimising by catch; (3) by catch sub-groups; (4) onboard observer programmes; and (5) seabird by catch mitigation measures. While the performance of Southern Ocean RFMOs is variable, other than CCAMLR, none have sufficient by catch reduction performance to warrant classification as protected areas.

2.3. Deployment of satellite tracking devices

Satellite transmitters were deployed on six northern and six southern giant petrels (four adults and two recently fledged juveniles of each species) between November 2005 and March 2006. A further seven satellite transmitters were deployed on recently fledged juveniles (three on northern giant petrels and four on southern giant petrels) during February and March 2007. All but one of the transmitters (Microwave Telemetry PTT-100 s) weighed approximately 40–45 g, measured $50 \times 30 \times 15$ mm and were duty cycled to transmit for eight hours on followed by 18 h off each cycle, giving each unit a potential battery life of 4–6 months. The remaining transmitter weighed 30 g, and measured $50 \times 15 \times 15$ mm. It was configured to duty cycle in the same way as the larger units, with a potential battery life of approximately three months. The larger transmitters were 1.73% of the lowest mass ever recorded for a giant petrel on Macquarie Island (an incubating female northern giant petrel), and less than 1.5% off the average masses of both genders of both species during the guard period (Johnstone 1977). Thus, the instruments fell well below the recommended 3% maximum mass- relative-to-body-weight for petrels (Phillips et al. 2003). The gender of birds was not determined because to do so would have necessitated taking morphometric measurements or collecting blood at capture, thereby requiring additional handling time. As breeding giant petrels at Macquarie Island are extremely wary and prone to abandoning nests when disturbed, to do this would have increased the risk of birds deserting nests.

Birds were captured by hand. Adult northern giant petrels attending small chicks were captured at the nest. Adult southern giant petrels were captured while resting on beach areas (away from the nest site) during the incubation stage, and their reproductive status ascertained by the condition of the brood patch. Three transmitters were attached to birds that had an appearance consistent with breeding birds and one was attached to a bird that was clearly not breeding. The latter bird had a band indicating that it had fledged from Macquarie Island in 1999, making it six years old (sub-adult) at the time of deployment. Fledgling chicks of both species were captured immediately prior or subsequent to leaving the nest. All devices were attached to feathers on the upper back using Tesa™ (Tesa AG, Hamburg, Germany) tape. This method has been used extensively on a range of albatross and petrel species and provides a good attachment while minimising any aerodynamic impact on the bird. In total we placed instruments on nine northern giant petrels (four breeding adults, five recently fledged juveniles) and 10 southern giant petrels (three breeding adults, one non-breeding adult, and six recently fledged juveniles). No attempt was made to recover devices from birds after they were placed on them, and all birds were tracked until either the device was lost or stopped transmitting.

2.4. Analyses of spatial use, time spent in management areas and fisheries overlap

Raw location data were downloaded from Argos (service Argos, Inc.) (.PRV format) and filtered for speeds >120 km h^{-1} using an iterative backwards/forwards filtering routing based on that recommended by McConnell et al. (1992) using the R package TRIP v0.0.3 (Sumner, 2006, http://www.staff.acecrc.org.au/~mdsumner/Rutas/). The filter speed was chosen based on pairs of successive high quality locations showing that birds are capable of sustaining such speeds. Most (97 ± 1.3%) locations were retained after filtering. TRIP was also used to interpolate between locations with a simple linear method at a resolution of one minute, and the resulting interpolated points were used to generate a time spent grid with 5×5 km cells. Cells with centroids within 5 km of Macquarie Island were discarded to reduce the weighting of time spent on the nest. Total times spent in management zones were then calculated by summing time spent within grid cells whose centroids lay within each zone. The 5 km grid cells were amalgamated into 50 km and 100 km wide cells using GIS software (MANIFOLD 7X PRO) for presentation purposes.

A hierarchical cluster analysis was conducted on the times spent in management zones by individual birds (as a % of the total time spent at sea) in order to quantify groupings in spatial use patterns. Euclidian distance was used as the dissimilarity measure and both Ward's minimum variance and single-linkage clustering methods were trialed. A one-way analysis of similarity (ANOSIM; Clarke 1993) was conducted to test whether groups determined by the cluster analysis were significantly different to one another. A principal components analysis was also conducted, and the relative contributions of management zones to the variance of the first three principal components were examined in order to evaluate which management areas were most important in separating behavioural groups.

Images of Antarctic sea ice concentration derived from AMSR-E (advanced microwave scanning radiometer) data (Kaleschke et al., 2001) were obtained from the Institute of Environmental Physics, Bremen, Germany, (http://www.iup.physik.uni-bremen.de:8084/amsredata/asi_daygrid_swath/l1a/s6250/). Images were converted to greyscale for presentation purposes, with darkest grey areas indicating 10% ice concentration and lightest areas indicating 100% ice concentration (therefore highlighting the ice margin and areas of coherent pack). These images were used in conjunction with giant petrel location information to examine the association between foraging activity and sea ice distribution. The extents of Southern Ocean currents and the positions of associated fronts are presented as the 20-year average of their locations (Orsi et al. 1995).

As there is a fishing operation in close proximity to the breeding colonies of the study birds and both species are known to associate with fishing vessels, the locations of trawls conducted by the single demersal trawler operating in the area during the tracking period in 2005–06 were overlaid on filtered locations during the same time period. These points were created from logbook data supplied by AFMA.

2.5. Banding and band return data

All northern giant petrel chicks surviving to fledging on Macquarie Island were banded in 1996 and 1997, with sub-samples of approximately 350 chicks banded in all subsequent years (DPIW, 2006). All southern giant petrel chicks surviving to fledging on Macquarie Island were banded in 1996, 1997 and 1999, with sub-samples of 400–500 chicks banded in subsequent years (DPIW, 2006). Band returns for each species were categorised by the number of years since fledging and their spatial distribution in relation to RFMOs was examined.

3. Results

From the 19 birds on which instruments were deployed, we obtained a total of 908 days of tracking data (48 ± 19 days per individual), with 7701 uplinks (405 ± 223 uplinks per individual) (Table 1). Of these locations, 97 ± 1% were retained after the velocity filter. After interpolation and griding of tracking data, data from grid centroids that fell within 5 km of Macquarie Island were discarded to remove the weighting of time spent at the nest when considering time spent at sea. This 'time at the nest' accounted for 22 ± 25% of the total tracking time for all birds considered together. For adult birds provisioning chicks, 41 ± 31% of the tracking period was spent 'at the nest', compared with only 11 ± 8% for recently fledged juveniles and 6.7% for the single non-breeding sub-adult that was tracked. Summary information for deployments and time spent within management zones are presented in Table 1.

3.1. *Adult giant petrels*

3.1.1. *Southern giant petrels*

Adult southern giant petrels undertook long southerly trips in the incubation phase of their breeding cycle. On these trips, birds concentrated activity around the Antarctic ice edge, the Polar front, and in the area between the Polar front and the Antarctic circumpolar current front (Fig. 3). These trips involved large amounts of time in CCAMLR statistical sub-areas 88.1 and 58.4.1 (Fig. 4, Table 1). Adults foraged in these areas between the 23rd of November 2005 and the 15th of January 2006. The single non-breeding sub-adult travelled further west than breeding birds, and foraged around the ice edge and in the pack ice until its tag ceased transmitting at the end of December. Later in the season, while provisioning chicks, foraging activity of breeding birds was concentrated close to Macquarie Island. Subsequent to the 16th of January, no locations were recorded outside the Macquarie Island EEZ. Most of this later activity was within the HPZ and the undesignated EEZ, with very little activity within the HSMZ (Fig. 4). A small amount of time was spent in the convention area of the WCPFC, while traversing the waters between the Macquarie Island EEZ and CCAMLR waters (Fig. 4, Table 1). One bird briefly passed through the IOTC convention area (Fig. 4, Table 1) while commuting between Macquarie Island and CCAMLR waters.

3.1.2. *Northern giant petrels*

Adult northern giant petrels primarily concentrated their foraging activity in waters close to Macquarie Island during chick rearing. As such, very little time was spent in management zones other than those contained within the Australian EEZ (Table 1). In December 2005 one individual undertook a longer trip, tracking along the Polar Front, and travelling through CCAMLR statistical sub-area 58.4.1 (Fig. 4), and into IOTC waters, where it remained for four days. Transmissions from this bird ceased while it was in these waters. All other foraging activity of adults occurred within 100 km of Macquarie Island's coast, with a majority of time being spent in the HPZ and outside the Marine Park area. Very little time was spent in the HSMZ (Fig. 4, Table 1).

3.2. *Fledgling giant petrels*

3.2.1. *Southern giant petrels*

Subsequent to fledging, recently fledged southern giant petrel juveniles spent a short time relatively close to Macquarie Island, both inside the MPA and in the greater EEZ area (Table 1) before travelling eastwards across the Pacific Ocean towards South America. On exiting the Australian EEZ, all but one individual spent time in New Zealand's EEZ before moving into international waters.

In 2006, both fledgling southern giant petrels travelled from Macquarie Island to the vicinity of the Antarctic ice edge in CCAMLR sub-area 88.1 during mid–late April, briefly traversing WCPFC waters en-route. Both individuals spent a short period near the ice edge before bearing northeast, and one also passed through sub-area 88.2. After leaving CCAMLR waters in late April, both fledglings spent the remainder of their time in high seas RFMO areas, and were in the vicinity of the South American shelf rise at the time that transmitters ceased functioning (May 2006, Fig. 5). This route took them through waters under the jurisdictions of WCPFC and the Inter American Tropical Tuna Commission (IATTC) and into SPRFMO/IATTC waters (Fig. 5, Table 1).

In 2007, two of the four recently fledged juveniles took relatively direct routes across the Southern Ocean, and reached or passed the southern tip of South America by the time their transmitters ceased functioning (in mid May and early June 2007). This route took both birds through CCSBT, WCPFC, IATTC and SPRFMO waters. These juveniles spent little or no time in CCAMLR sub-areas 88.1, 88.2, and did not spend time in the vicinity of the ice edge until they were close to South America. One of these birds passed through CCAMLR sub-area 88.3 in early May en-route to the area of the Palmer Archipelago, where it remained until its transmitter ceased functioning in mid May. The other did not utilise CCAMLR waters until late May and early June 2007, when it spent time visiting the ice edge to the west of the Antarctic Peninsula after passing the southern tip of Cape Horn (CCAMLR subareas 48.1 and 48.2). The remaining two juveniles took less direct routes across the Southern Ocean. One spent time in CCAMLR sub-areas 88.1 and 88.2 throughout April, before heading northward in WCPFC waters to approximately 45° S, where it remained until its transmitter ceased functioning at the end of April. The other moved backwards and forwards between CCAMLR sub-areas 88.1 and 88.2 and WFPFC waters, gradually tending west, and had not travelled further west than sub-area 88.2 by the time its transmitter ceased functioning in June 2007 (see Fig. 6).

3.2.2. *Northern giant petrels*

In both years, northern giant petrel fledglings followed broadly similar routes to the southern giant petrel fledglings, travelling towards the South American continental shelf across the Pacific Ocean. However, unlike the recently fledged

Table 1 – Percentage of time at sea spent by southern and northern giant petrels in Southern Ocean management zones during the austral summers of 2005/06 and 2006/07

year	Sp.	Age category	days deployed	Number of uplinks	locations retained after filter %	days at sea	% of total time at sea spent within management zones: Zones Surrounding Macquarie Island: EEZ	Marine Park HS MZ	Marine Park HPZ	NZ EEZ	CCAMLR Statistical Sub-areas: 88.1	88.2	58.4.1	88.3	48.1	48.2	Other RFMO Areas: IOTC	CCSBT/WCPFC	CCSBT	WCPFC	WCPFC/IATTC	WCPFC/IOTC	IATTC	IATTC/SPRFMO	SPRFMO	Un-regulated
06	N	B	46.0	375.0	94.9	11.4	8.2	6.0	85.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
06	N	B	34.0	157.0	98.7	33.7	7.4	-	92.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
06	N	B	9.0	47.0	97.9	8.8	26.0	4.8	11.8	-	-	-	20.6	-	-	-	30.2	-	-	5.7	-	0.9	-	-	-	-
06	N	B	29.0	304.0	97.0	6.4	27.6	5.3	67.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
06	N	All B	29.5 ± 15.4	220.8 ± 147.2	97.1 ± 1.6	60.3 ± 12.6	17.3 ± 11	4 ± 2.7	64.3 ± 36.6	-	-	-	5.2 ± 10.3	-	-	-	7.5 ± 15.1	-	-	1.4 ± 2.8	-	0.2 ± 0.5	-	-	-	-
06	N	F	35.0	322.0	98.1	30.2	1.2	9.3	6.7	7.5	-	-	-	-	-	-	-	14.8	-	57.7	-	-	-	-	-	2.9
06	N	F	27.0	237.0	97.9	20.8	11.6	4.1	3.0	11.5	-	-	-	-	-	-	-	13.3	-	7.2	21.1	-	7.8	15.6	4.9	-
06	N	All F	31 ± 5.7	279.5 ± 60.1	98 ± 0.2	50.9 ± 6.6	6.4 ± 7.3	6.7 ± 3.7	4.8 ± 2.6	9.5 ± 2.8	-	-	-	-	-	-	-	14 ± 1	-	32.4 ± 35.7	10.6 ± 5.5	-	3.9 ± 5.5	7.8 ± 11	2.4 ± 3.5	1.4 ± 2
07	N	F	52.0	558.0	96.1	45.8	2.5	0.2	3.3	15.0	-	-	-	-	-	-	-	5.1	-	43.0	8.5	-	3.9	18.5	-	-
07	N	F	59.0	741.0	97.7	46.7	1.7	3.3	3.8	5.8	-	6.5	-	-	-	-	-	12.7	-	12.0	-	-	0.2	10.6	29.0	14.5
07	N	F	49.0	382.0	97.6	47.5	-	3.5	4.8	3.2	-	-	-	-	1.1	-	-	5.1	11.7	9.0	-	-	0.2	30.1	17.7	13.7
07	N	All F	53.3 ± 5.1	560.3 ± 179.5	97.1 ± 0.9	14-.8	1.4 ± 1.3	2.3 ± 1.9	4 ± 0.8	8 ± 6.2	-	2.2 ± 3.8	-	-	0.4 ± 0.6	-	-	7.6 ± 4.4	3.9 ± 6.7	21.3 ± 18.8	2.8 ± 2.1	-	1.4 ± 2.1	19.7 ± 9.8	15.6 ± 14.6	9.4 ± 8.2
06	S	B	63.0	698.0	96.0	42.1	11.8	3.4	22.5	-	13.2	-	45.3	-	-	-	0.6	-	-	2.1	-	1.0	-	-	-	-
06	S	B	73.0	749.0	97.2	32.7	17.5	4.5	16.8	-	10.2	-	46.0	-	-	-	-	-	-	5.1	-	-	-	-	-	-
06	S	B	3-	137.0	95.6	15.6	36.7	5.0	21.4	-	27.1	-	-	-	-	-	-	-	-	9.9	-	-	-	-	-	-
06	S	All B	64.5 ± 18.6	528 ± 339.6	96.3 ± 0.8	90.4 ± 13.4	22 ± 13	4.3 ± 0.8	20.2 ± 3	-	16.8 ± 9	-	30.4 ± 26.3	-	-	-	0.2 ± 0.4	-	-	5.7 ± 3.9	-	0.3 ± 0.6	-	-	-	-
06	S	NB	4-	413 ± 0	94.9 ± 0	37.3 ± 37.3	-	0 ± 2.2	3 ± 3	-	88.8 ± 0	-	-	-	-	-	-	-	-	6 ± 6	-	-	-	-	-	-
06	S	F	52.0	583.0	98.6	51.0	23.8	6.6	0.5	-	15.0	-	-	-	-	-	-	-	-	5.6	4.8	-	2.1	41.7	-	-
06	S	F	52.0	60-	98.5	49.1	5.5	13.5	13.2	5.7	6.3	8.5	-	-	-	-	-	-	-	5.0	-	-	-	38.2	2.6	1.5
06	S	All F	52 ± 0	591.5 ± 12	98.6 ± 0.1	100.1 ± 1.3	14.7 ± 12.9	10 ± 4.9	6.8 ± 9	2.9 ± 4.1	10.6 ± 6.1	4.2 ± 6	-	-	-	-	-	-	-	5.3 ± 0.4	2.4 ± 1.5	-	1 ± 1.5	40 ± 2.5	1.3 ± 1.8	0.7 ± 1
07	S	F	78.0	157.0	96.8	73.6	2.0	8.4	5.8	3.1	-	13.5	-	-	-	5.3	-	3.8	-	17.1	-	-	-	-	27.7	13.5
07	S	F	8-	691.0	95.2	70.3	4.8	2.3	3.1	2.0	0.1	29.5	-	-	-	-	-	-	-	56.4	-	-	-	-	-	1.8
07	S	F	4-	267.0	97.8	38.4	0.2	1.6	8.8	4.0	8.3	24.3	-	-	-	-	-	13.4	-	39.5	-	-	-	-	-	-
07	S	F	6-	283.0	99.3	45.2	5.7	3.0	8.9	7.9	-	-	-	2.0	12.2	-	-	15.3	-	19.9	4.3	-	-	-	16.1	4.9
07	S	All F	64.5 ± 18.6	349.5 ± 234.5	97.3 ± 1.7	227.5 ± 17.6	3.1 ± 2.5	3.8 ± 3.1	6.6 ± 2.8	4.3 ± 2.5	2.1 ± 4.1	16.8 ± 13	-	0.5 ± 1	3 ± 6.1	1.3 ± 2.7	-	8.1 ± 7.4	-	33.2 ± 18.4	1.1 ± 0	-	-	-	10.9 ± 13.5	5 ± 6

White rows are for individual birds, grey rows indicate averages ± s.d. for each age/year class. (N = northern giant petrel, S = southern giant petrel, F = fledgling, B = breeding adult, NB = non-breeding adult).

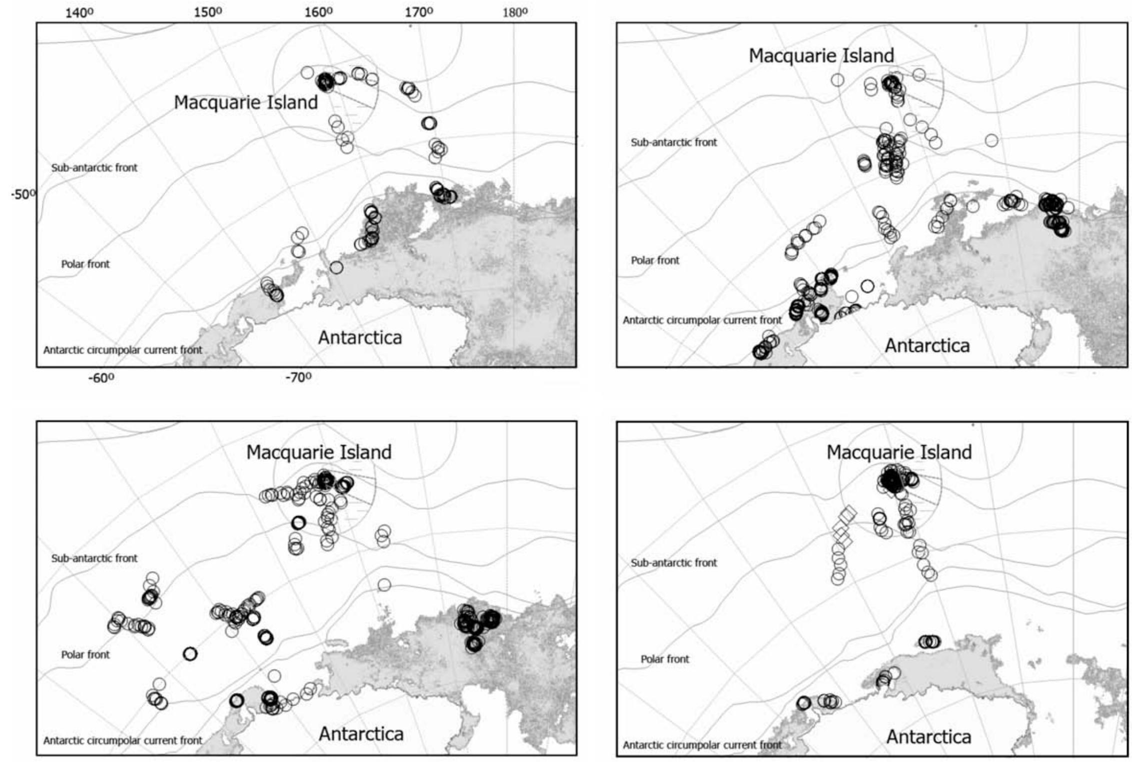

Fig. 3 – Filtered locations of foraging adult southern giant petrels from the 20–30th of November (top left), from the 1st–15th of December (top right), from the 16th–31st of December (bottom left), from the 1st–15th of January (circles, bottom right) and the 16th of January onwards (diamonds, bottom right). Ice edge images are from the 28th November, 11th December, 23rd December and 14th of January respectively. Darkest areas indicate 10% ice concentration, lightest areas indicate 100% ice concentration.

southern giant petrel juveniles, northern giant petrel juveniles did not travel south at the beginning of their journeys, and therefore, three out of five individuals did not spend any time in areas under CCAMLR's jurisdiction. In 2007 one individual detoured into CCAMLR sub-area 88.2 in early March, and another individual briefly passed through CCAMLR sub-area 48.3 in late-March 2007, after passing Cape Horn.

In both years, the routes taken by all fledglings initially took them into the New Zealand EEZ on leaving the Macquarie Island EEZ. From here they travelled west across the Southern Ocean towards the coast of South America, moving through waters administered by CCSBT, WCPFC, IATTC and SPRFMO (Fig. 5, Table 1). In 2006, trackers lasted 31 ± 6 days, and neither of the recently fledged juveniles had yet reached the east coast of South America by the time transmissions ceased (Fig. 5). Transmitters lasted longer in 2007 (53 ± 5 days), and all three juveniles reached the east coast of South America (on the 16th, 17th and 24th of March) before transmissions ceased. Transmissions ceased for one of these birds on the same day that it reached the South American coast. The remaining two juveniles both travelled around the tip of Cape Horn before transmissions ceased. One spent a large amount of time in the fjords of Terra del Fuego, and was 45 km east of Staten Island when transmissions ceased. The other remained offshore, travelling more rapidly, and was approximately 3000 km east of Cape Horn, in CCSBT waters, at the time of the last PTT uplink.

3.3. *Behavioural groupings*

Fledgling giant petrels grouped separately from adults when subjected to multivariate clustering techniques on the basis of the percentage of the total time at sea spent in each management zone. The three breeding adult northern giant petrels that only foraged near-shore (provisioning trips) grouped separately to other birds, with the pattern of RFMO utilisation of the northern giant petrel adult that undertook a longer oceanic trip (incubating) grouping with that of breeding adult southern giant petrels. The pattern of RFMO use of the one non-breeding sub-adult southern giant petrel grouped separately to all other birds that were tracked. The RFMO use regimes of individual fledgling giant petrels generally grouped most closely with other individuals of the same species, however, the RFMO use patterns of northern and southern giant petrel fledglings did not separate into two distinct groups.

The groupings described above were consistent between clustering methods (Ward and single-linkage; both using Euclidian distance) for cluster analysis and for PCA. A one-way ANOSIM indicated that behavioural groups (fledglings, provisioning adults, incubating adults, non-breeding sub-adult) were significantly different to one another ($p < 0.001$,

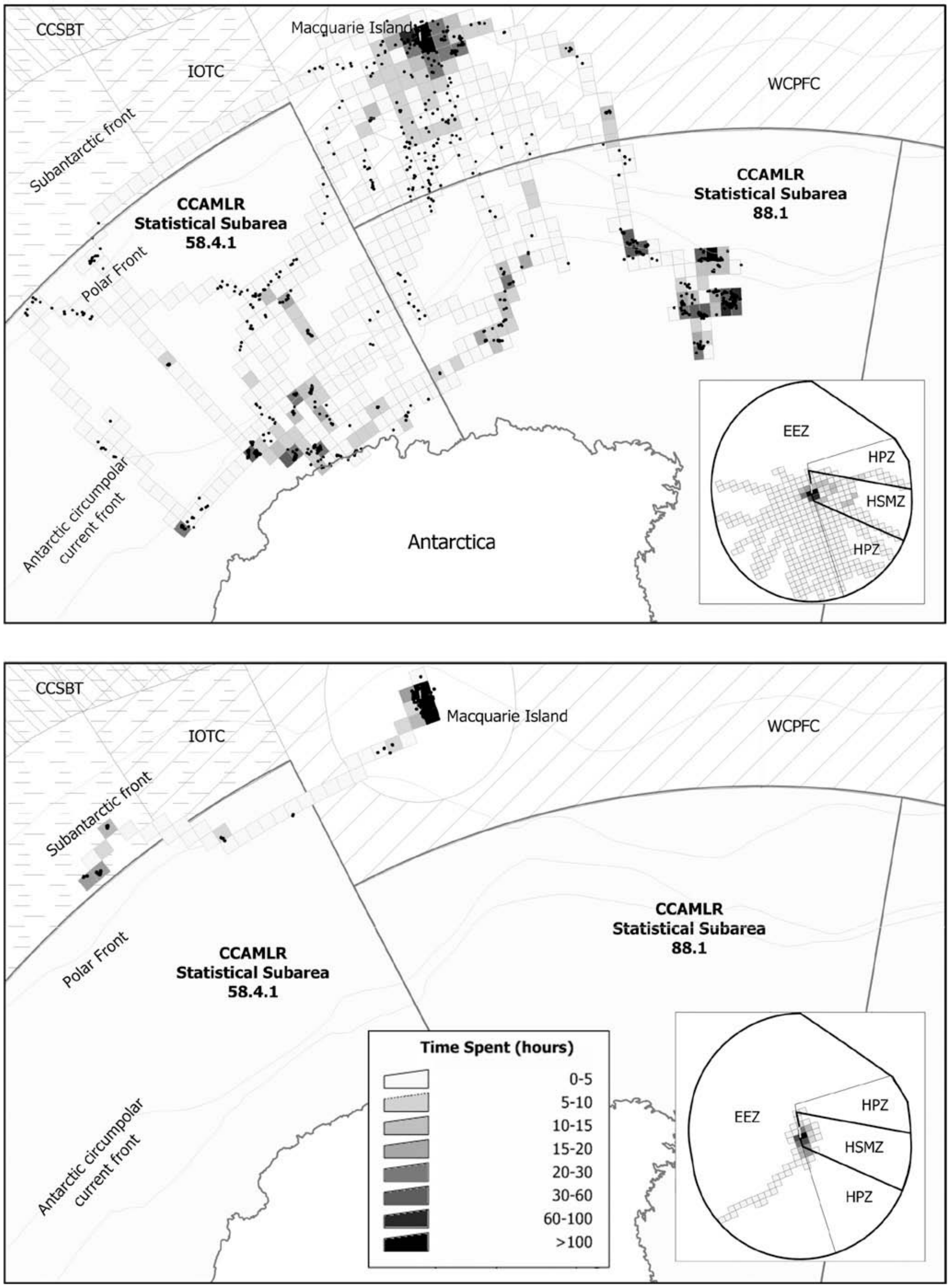

Fig. 4 – Time spent within 50 × 50 km grid cells by (top) adult southern giant petrels between November 2005 and January 2006 (*n* = 4) and (bottom) adult northern giant petrels (*n* = 4) between November 2005 and February 2006. Black points indicate individual filtered locations. Insets show time spent within 20 km × 20 km grid cells in the Macquarie Island EEZ.

ANOSIM statistic $R = 0.68$). The PCA indicated that the amounts of time spent in the HPZ, CCAMLR sub-areas, and WCPFC were most important in distinguishing behavioural groups.

3.4. *Band returns*

Twenty seven bands were recovered from southern giant petrels and forty two from northern giant petrels away from Macquarie Island between January 1996 and March 2006.

The majority of these band returns were from birds in the first year after fledging (Table 2). Most first year band returns were from New Zealand and South America for both species, with fewer recoveries from South Africa, Australia and at sea. Bands from southern giant petrels were mainly recovered in and around the South Pacific Ocean, while a large number of bands were recovered from in and around the Atlantic and Indian Oceans for northern giant petrels (Fig. 7).

The majority of recoveries from birds in their 3rd year after fledging or older were made in the region between

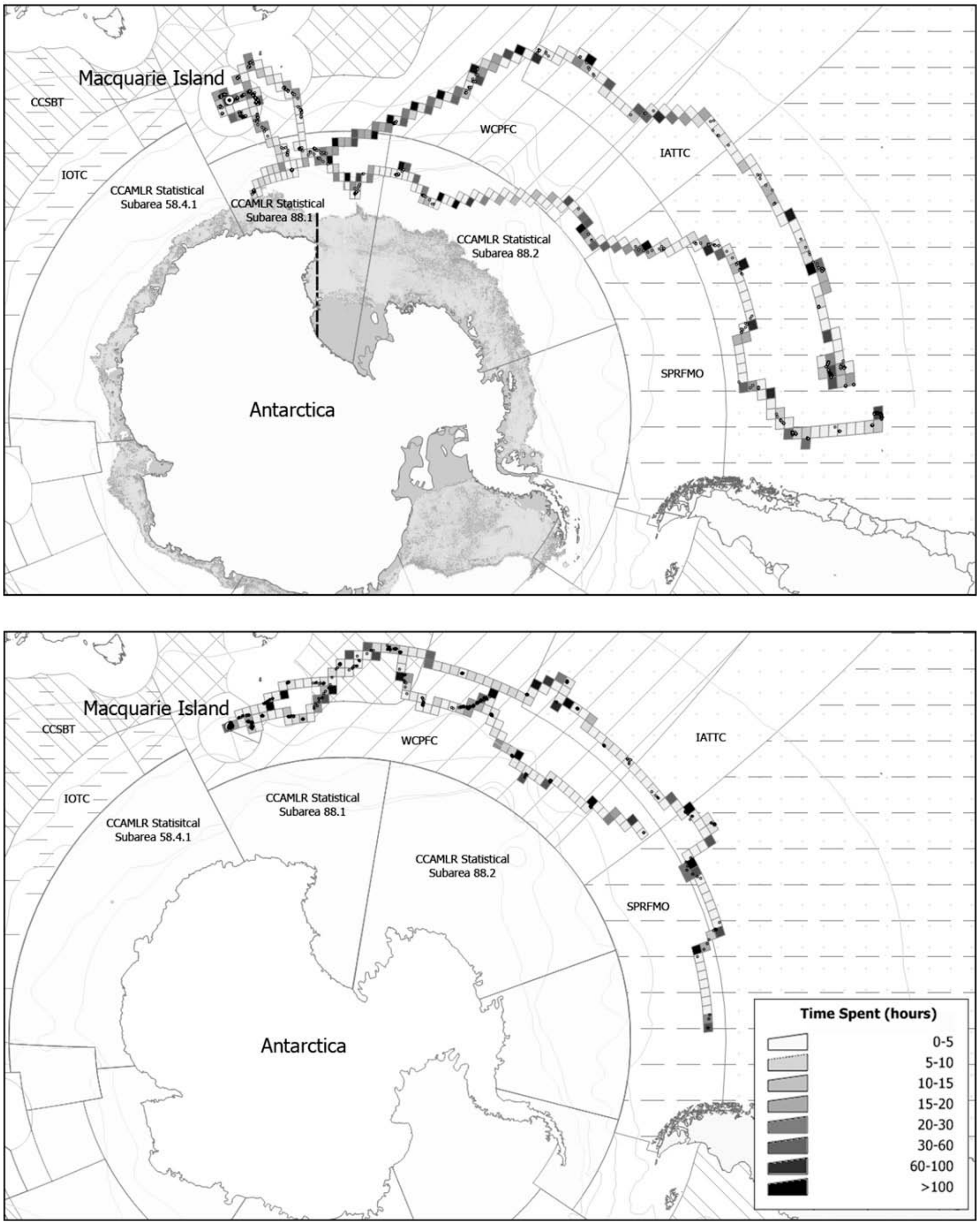

Fig. 5 – Time spent within 100 × 100 km grid cells by (a – top panel) fledgling southern giant petrels between February and May 2006 ($n = 2$), and (b – bottom panel) fledgling northern giant petrels between February and March 2006 ($n = 2$). In the top panel the ice edge image to the left of the dotted line is from the 22nd of April and the image to the right of the line is from the 16th of April, corresponding to the days on which birds were in the vicinity of the ice edge in each area. Dark grey areas represent 10–90% ice concentration, and light grey areas indicate 90–100% ice concentration.

the west coast of South Africa and New Zealand, with all recoveries from birds in their fifth year or older being made in New Zealand. The oldest southern giant petrel from which a band was recovered was collected in New Zealand in its 5th year after fledging; the oldest northern giant petrel was also collected in New Zealand, in its 8th year after fledging.

The number of band returns within and around the land masses surrounding RFMOs are presented in Table 3. For southern giant petrels, 44% of bands were recovered from the New Zealand EEZ, with high proportions of band returns also recorded in all other RFMOs considered other than CCAMLR (4%) and IOTC (4% – in the area also under the jurisdiction of WCPFC). For northern giant petrels, the management areas that yielded the greatest proportions of band returns were the Australian and New Zealand EEZs (24% and 21%, respectively), CCSBT (24%), ICCAT (19%), SPRFMO/IATTC (17%) and IOTC (12%).

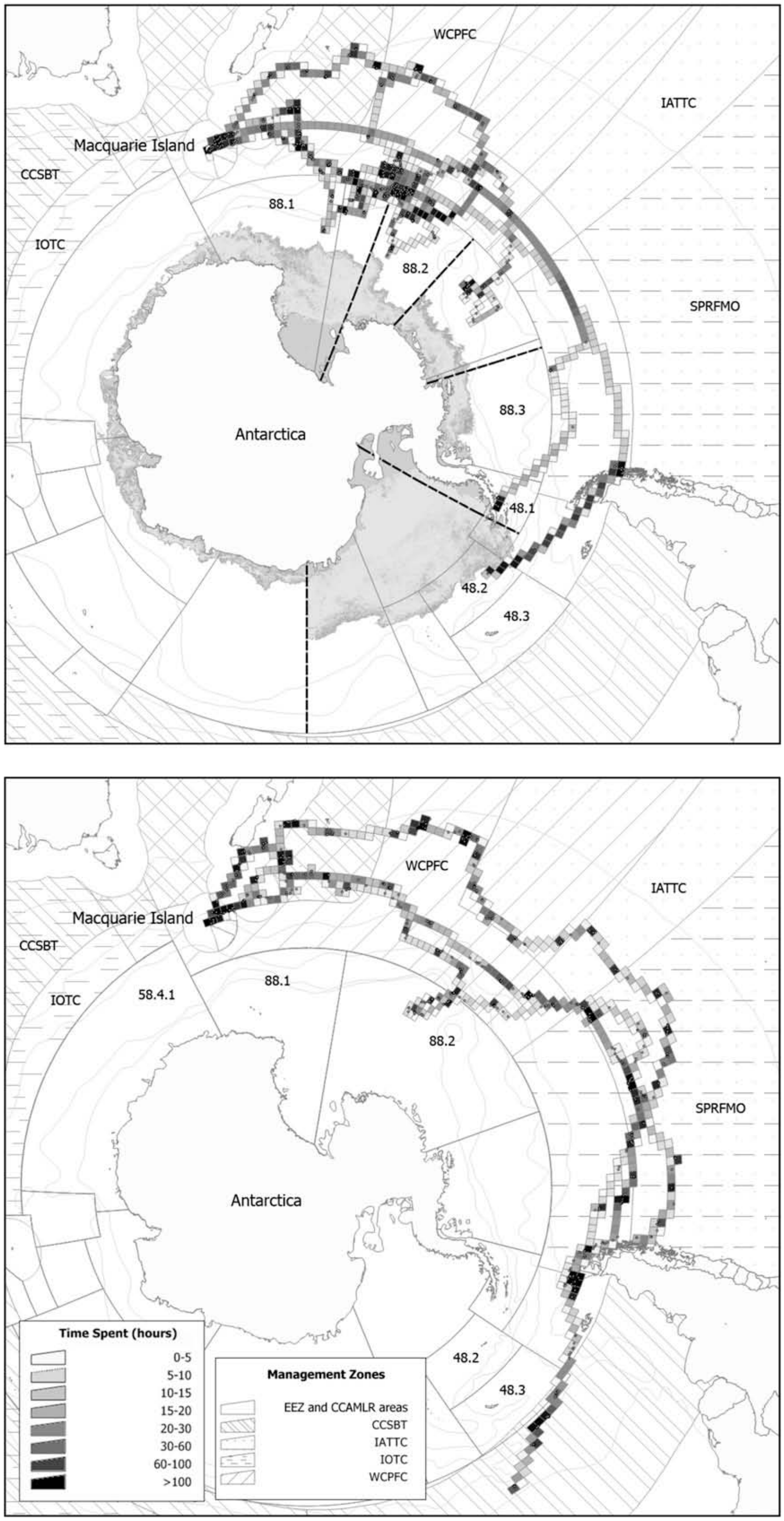

Fig. 6 – Time spent within 100 × 100 km grid cells by (top panel) fledgling southern giant petrels (*n* = 4) between February and June 2007, and (bottom panel) fledgling northern giant petrels (*n* = 3) between February and April 2007. In (a) the ice edge images are from (moving clockwise from the top) the 4th of April, the 20th of April, the 29th of May, the 14th of May and the 4th of June, corresponding to the days on which birds were in the vicinity of the ice edge in each area. Dark grey areas represent 10–90% ice concentration, and light grey areas indicate 90–100% ice concentration.

Table 2 – Distribution of band recoveries between 1996 and 2006 of northern (*M. halli*) and southern (*M. giganteus*) giant petrels banded at Macquarie Island

	Age category	% Of total recoveries	Australia	Kerguelen	New Zealand	South Africa	South America	South Pacific	At sea	Total
M. halli	1st yr	51	3		5	2	6		5	21
	2nd yr	24	4			1	4		1	10
	3rd yr	15			1	2	1		2	6
	4th yr	2							1	1
	⩾5th yr	7			3					3
	Total		7		9	5	11		9	41
M. giganteus	1st yr	74	2		9	1	3	1	4	20
	2nd yr	11			1	1	1			3
	3rd yr	4				1				1
	4th yr	7		1	1					2
	⩾5th yr	4			1					1
	Total		2	1	12	3	4	1	4	27

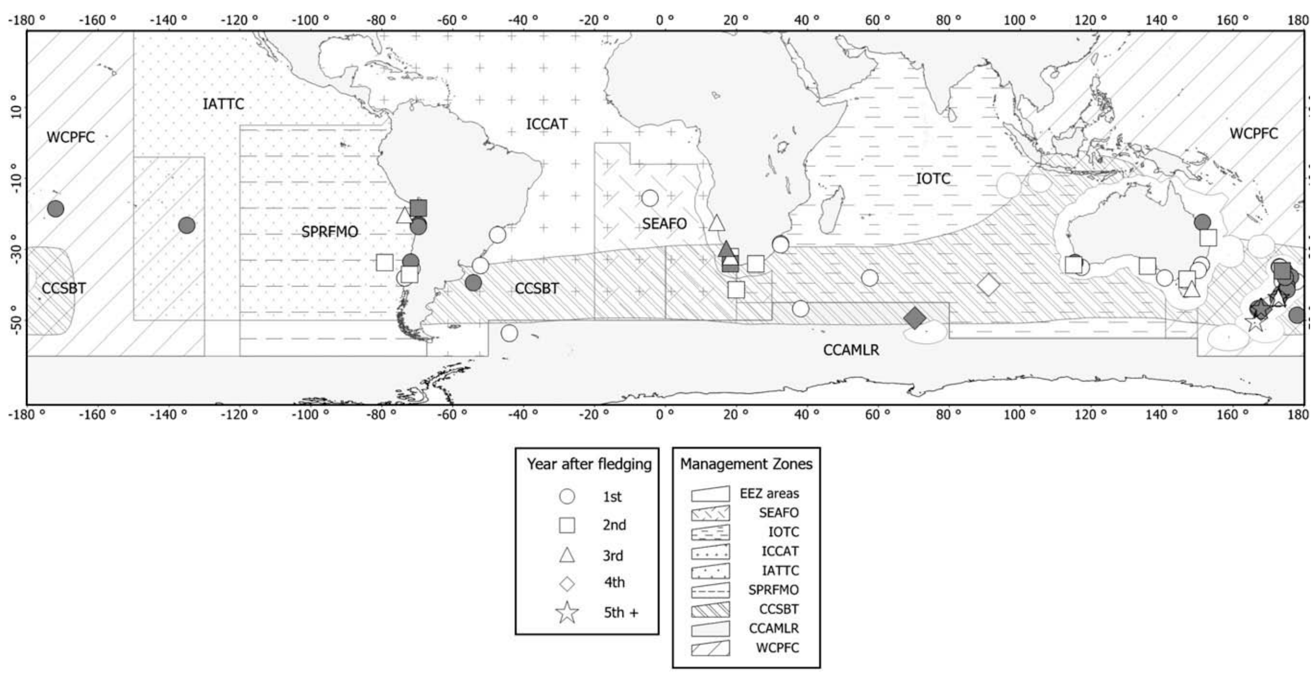

Fig. 7 – The distribution of band recoveries between 1996 and 2006 for northern and southern giant petrels banded on Macquarie Island. Filled grey points represent southern giant petrel band recoveries, and open points represent northern giant petrel band recoveries.

3.5. *Overlap with the Macquarie Island Patagonian toothfish fishery*

The trawl vessel operated within the Macquarie Island fishery between the 3rd and the 27th of February in 2006, fishing along the Macquarie Island ridge line, with a majority of shots conducted to the north and east of the Island. There was substantial spatial and temporal overlap between the areas used by recently fledged juvenile northern giant petrels and this fishing vessel between the 4th and the 21st of February (Fig. 8). While northern giant petrel adults and southern giant petrels (both recently fledged juveniles and adults) also foraged in this area, they were not present during the same period as the fishing vessel.

4. Discussion

4.1. *Utilisation of marine protected areas*

Breeding adult southern and northern giant petrels spent a significant proportion of their time at sea in the Macquarie Island Marine Park (25 ± 3% and 68 ± 36%, respectively). For southern giant petrels, most of this time was during chick provisioning, with longer trips to CCAMLR waters predominating

Table 3 – Band returns (total number and percentages of total) within and around the borders of management areas, between 1996 and 2006

	Species	n	EEZ areas						RFMOs					
			Australia	New Zealand	CCAMLR	IOTC	ICCAT	CCSBT	WCPFC	IOTC/CCSBT	ICCAT/CCSBT	IATTC/WCPFC	ICCAT/SEAFO/CCSBT	SPRFMO/IATTC
Total	*M. giganteus*	27	2	12	1	0	0	5	1	0	4	1	–	5
	M. halli	41	10	9	2	2	2	8	–	2	5	–	1	7
	Combined	**68**	**12**	**21**	**3**	**2**	**2**	**12**	**1**	**2**	**9**	**1**	**1**	**12**
% of total	*M. giganteus*		7	44	4	0	0	19	4	0	15	4	0	19
	M. halli		24	22	5	5	5	20	0	5	12	0	2	17
	Combined		**18**	**31**	**4**	**3**	**3**	**19**	**1**	**3**	**13**	**1**	**1**	**18**

earlier during incubation. Although adult northern giant petrels were not tracked prior to chick rearing, a long southerly trip undertaken by one individual early in the deployment period may indicate that adults of this species also spend less time in the Marine Park earlier in the reproductive cycle. Fledglings of both species spent much of the first week at sea in the Marine Park (14 ± 9% of the total time at sea during the tracking period in 2006 and 9 ± 4% in 2007), before moving into international waters.

A majority of the time that adult giant petrels spent in the Macquarie Island Marine Park was spent in the HPZ (20 ± 3% and 64 ± 36% of total time at sea for southern and northern giant petrels respectively), with relatively little time (4 ± 3% of the total time at sea for both species) spent in the HSMZ. While management prescriptions vary between these zones, given the prohibition of fishing activities in the HPZ, we consider that they afford significant protection to both northern and southern giant petrels during time spent in these areas.

Further from Macquarie Island, the most important foraging areas for adult giant petrels during the breeding season were CCAMLR statistical sub-areas 58.4.1 and 88.1. These areas were used most extensively by southern giant petrels, with breeding birds spending 30 ± 26% of the total time at sea in sub-area 58.4.1 and 17 ± 9% in 88.1; and 89% of the total time at sea spent in 88.1 by one non-breeding bird. Within these areas, birds concentrated their foraging activity around the ice edge and the Polar Frontal Zone, both of which are known to be highly productive areas, extensively utilised by Southern Ocean vertebrates (Jonker and Bester, 1998; Catard et al., 2000; Boyd et al., 2002; Catry et al., 2004; Field et al., 2004), and where giant petrels would likely have good access to live marine prey and carrion.

CCAMLR statistical sub-areas 88.1 and 88.2 were also important for southern giant petrel fledglings (accounting for 5 ± 6% and 13 ± 12% of the total time at sea respectively), which spent time in these zones while visiting the area of the Antarctic ice edge. Sub-areas 48.1, 48.2 and 88.3, in the region of the Antarctic Peninsula, were also utilised by individual fledglings late in the tracking period in 2007.

CCAMLR statistical sub-area 58.4.1 is classified as 'average-low risk' and 88.1, 88.2, 88.3 and 48.1 as 'low risk' against a five-point scale of potential risk of interaction between seabirds and longline fisheries (risk levels 2 and 1, respectively, in a ranking system where risk level 5 represents high risk) (SC-CCAMLR XXIII 2004). Even though the number of hooks set in these three CCAMLR regions has increased considerably in recent years, no seabird by catch has been reported by observed and regulated fisheries in the last eight years (SC-CCAMLR XXIII, 2004). The numbers of hooks set, and hence seabird by catch levels, in illegal, unreported and unregulated (IUU) fisheries in these areas are considered likely to be low (Tuck et al., 2003; SC-CCAMLR XXIII, 2004).

4.2. *Overlap with the Macquarie Island Patagonian toothfish fishery*

We found significant temporal and spatial overlap between the areas used by recently fledged northern giant petrel juveniles near Macquarie Island and the areas utilised by the single trawl vessel that was licensed to operate in these waters in

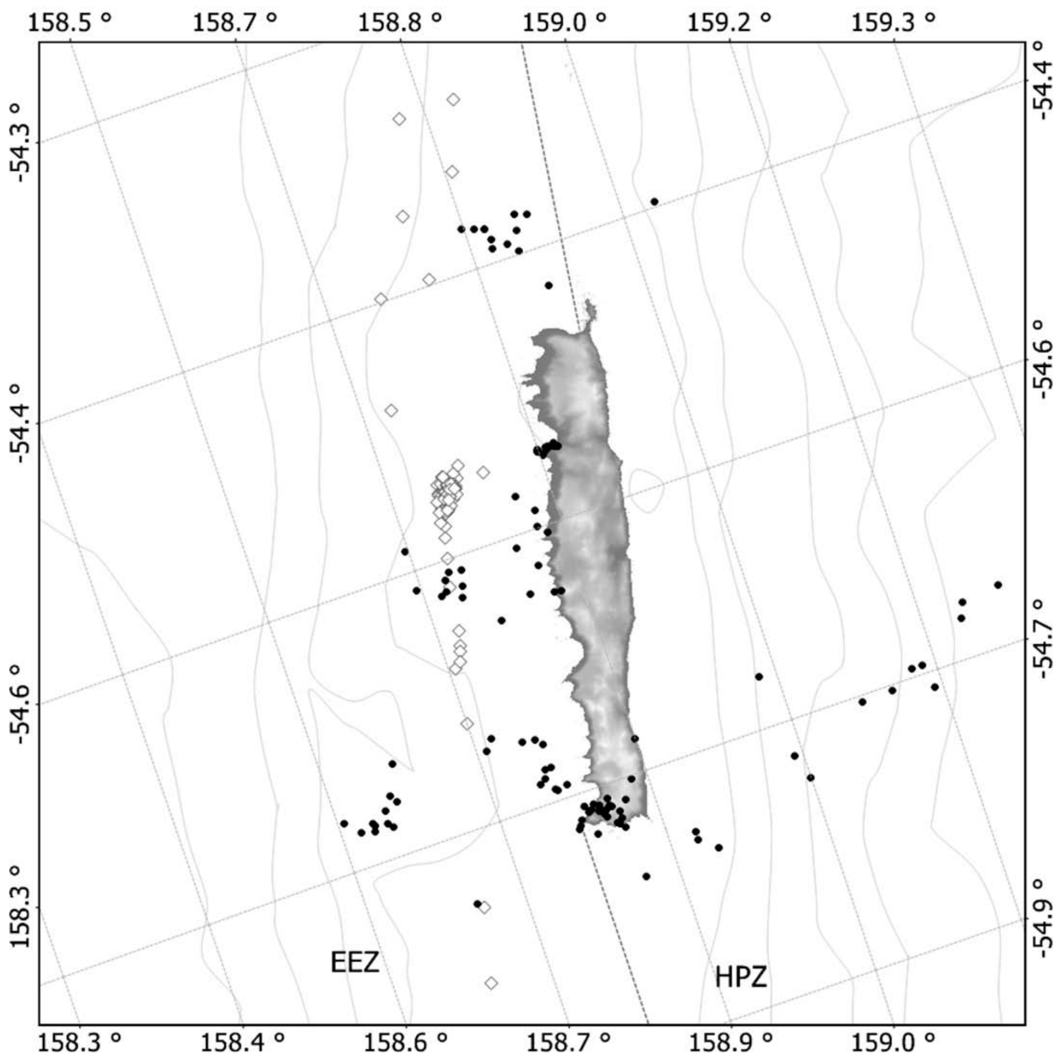

Fig. 8 – The distribution of trawl shots (diamonds) and the velocity filtered locations of fledgling northern giant petrel chicks in waters surrounding Macquarie Island between the 4th and 21st of February 2006.

2006. Although none of the devices deployed on adults of either species were still transmitting at this time, adult giant petrels of both species spent time in this area earlier in the season, and we consider it likely that adult birds, especially northern giant petrels, would also have been present at the time when the fishing boat was present. This assertion is supported by observer reports that northern giant petrels are the most abundant seabird attending the vessel (AFMA fisheries observers, unpublished). Recently fledged southern giant petrels also used a similar area at times when they were tracked close to the island. The overlap between the fishery and giant petrels of both species provides an indication that foraging birds and Patagonian toothfish both exploit the same highly productive zone (Goldsworthy et al., 2001; Terauds et al., 2006).

In recent years, the Patagonian toothfish quota in the fishery has been very low and hence the fishery has operated for only a short period of time each year. However, the timing of fishing effort has varied somewhat each year, principally based over the Austral summer and occurring in all months from October through to March, which has potential impacts for both southern and northern giant petrels. For example, if fishing occurred four to six weeks later than it did in 2006, the risk posed by the fishery to recently fledged southern giant petrel fledglings would have been greater in that year. Similarly, increased annual quotas could see the fishing season extend across the summer months, and at times when breeding adult giant petrels are foraging extensively near Macquarie Island.

In assessing the impact of the current trawl fishery, it is noteworthy that no seabird deaths or serious injuries have been recorded by observers to date (Weinecke and Roberston, 2002). However, observations have not been made during towing, when birds interacting with trawl warps are likely to be lost (Bartle, 1991; Weimerskirch et al., 2000) or unobserved (Sullivan and Reid, 2003). As highlighted by Baker et al. (2002), it will not be possible to reliably assess levels of seabird by catch during trawl operations until observer programs focus on this issue, as well as remaining vigilant on other aspects of the fishing operation.

4.3. Utilisation of regional fisheries management organisation areas

4.3.1. Satellite tracking data

Fledgling southern and northern giant petrels spent considerable time (56 ± 5% and 78 ± 6% of total time at sea during the tracking period) on the high seas of the Pacific Ocean, in areas under the jurisdictions of CCSBT, WCPFC, IATTC and SPRFMO. In these areas, the level of risk posed by both legal and illegal fisheries is far less clear than in the protected areas described above, but, as the by catch reduction performance by these RFMOS is considerably lower (Small, 2005) the risk is likely to be correspondingly increased. As highlighted by Cooper (2002), a dichotomy exists between seabird conservation nations and the high seas fishing nations.

Breeding adult giant petrels spent relatively little time in RFMO areas other than CCAMLR. IOTC and WCPFC waters were briefly traversed by adult southern giant petrels travelling to CCAMLR waters. One adult northern giant petrel apparently foraged in IOTC waters, and was still in this zone when its transmitter ceased functioning.

4.3.2. Band return data

The general finding from banding studies has been that, on fledging, giant petrel juveniles tend to disperse in an easterly direction and travel great distances, often circumnavigating the Southern Ocean (perhaps several times), before returning to their natal colonies (Trivelpiece and Trivelpiece, 1998). The paths taken by recently fledged juvenile giant petrels in the current study are consistent with this pattern, and supported by the observed distribution of band returns. The banding data are also extremely useful in inferring the importance of RFMOs beyond the range of satellite trackers attached on Macquarie Island. Returns indicate that the ICCAT and SEAFO areas are likely to be extensively utilised by Macquarie Island giant petrels in the first three years after fledging – a pattern that would not be detectable from satellite tracking data alone because of the limited lifespan of attachments of devices.

4.4. Implications: conservation, management and future directions

During the breeding season adult giant petrels are well served by the network of MPAs adjacent to Macquarie Island, though the level of protection has the potential for improvement. The formation of a Marine Park within the Macquarie Island EEZ was a progressive move to protect top-order predators, but ongoing assessment is required as additional information is obtained (Terauds et al., 2006).

It is noteworthy the Marine Park boundaries were declared prior to studies of the at sea movements of Macquarie Island's seabird populations. In light of the management goals that aim to 'protect foraging marine mammals and seabirds from direct human disturbance', we suggest that the findings of this study, together with those of Terauds et al. (2006) and Field et al. (2006), warrant a re-assessment of the extent of the Marine Park and the zone boundaries. Information on the foraging activities of northern giant petrels during the incubation phase of the breeding cycle needs to be collected, and will be important for the development of management strategies for fisheries in these waters.

The overlap between the Macquarie Island Patagonian Toothfish fishery and foraging giant petrels, particularly northern giant petrels, supports the cautious approach taken by the Australian Government in its management of this fishery to date. Prohibition of offal discharge, 100% observer coverage and the employment of extensive mitigation measures all serve to minimise the threats posed to giant petrels and other seabirds breeding on Macquarie Island. We recommend that these current management measures are maintained. A recent decision to expand the fishery to permit operation of a longline vessel in the area will require adoption of strict environmental measures, accompanied by high levels of observer coverage, to ensure interactions between this gear type and giant petrels (and other seabird species) are minimised. The prescriptions for the longline fishery include limits on seabird by catch (ranging from 1 to a maximum total of three, depending on species). We recommend that these limits are also imposed upon the trawl fishery operating in this region.

While banding studies were once widely used for migration studies, development of biotelemetry techniques has seen valuable banding datasets largely overlooked in recent years. This study clearly illustrates that banding data can be indispensable in comprehensively assessing the areas utilised by wide ranging seabirds. It provides an invaluable complement to biotelemetry, helping to fill the gaps caused by the limitations of cost, battery life, attachment, and/or the need to retrieve the instrument to recover data. We encourage other researchers to consider greater use of complementary banding data sets for this purpose.

BirdLife International (2005) identified ICCAT (International Commission for the Conservation of Atlantic Tuna), CCAMLR and CCSBT as being the most important RFMOs in terms of overlap with giant petrel distributions. This was based on distribution data from populations in the Atlantic sector of the Southern Ocean (Trivelpiece and Trivelpiece, 1998; González-Solís et al., 2002). This study has shown that WCPFC and IATTC and SPRFMO are also extremely important in the months following fledging for giant petrels from Macquarie Island. These areas are also likely to be important following fledging for giant petrels from other populations in the Pacific Sector of the Southern Ocean (most notably the New Zealand subantarctic islands for northern giant petrels and locations along the Antarctic coasts of the Davis and Dumont d'Urville Seas for southern giant petrels). We suggest that the areas used by giant petrels fledged from Macquarie Island are also likely to be used by fledglings from colonies in the Atlantic sector in the course of their circumnavigations of the Southern Ocean prior to returning to their natal colonies.

Currently CCAMLR is unique among Southern Ocean RFMOs in having adopted and fully implemented a comprehensive set of measures to reduce seabird by catch. CCSBT has established a requirement for streamer (Tori) lines to be used south of 30° S, but, as noted by BirdLife International (2005), the overall effectiveness of and compliance with this measure is unknown. However, the information available does not indicate that these measures, if used, are effective. Between 1995 and 2003 it has been estimated that Japanese vessels fishing under the auspices of the CCSBT have killed

690 giant petrels each year, a level of by catch that could well be unsustainable in the longer term (CCAMLR 2005). Similarly, IOTC and SEAFO have introduced conservation measures to mitigate seabird by catch, but the level of enforcement and effectiveness of these measures is not clear. ICCAT and WCPFC do not yet require vessels to use any seabird by catch mitigation measures (Small, 2005).

CCAMLR has illustrated the possibilities of RFMO action, having reduced albatross and petrel by catch in its regulated fisheries by over 99% (SC-CCAMLR XXIII 2004). Under the international legal framework for the oceans, other RFMOs also have the duty to take action to minimise by catch of vulnerable non-target species such as albatross and petrels (BirdLife International, 2005). However, the conventions of some RFMOs have not yet been updated to reflect the new international legal framework for the oceans (e.g. the UN Fish Stocks Agreement), which has greatly expanded the role of RFMOs and established key principals for sustainable ocean management. We support the assertion of Small (2005) that updating these RFMO conventions will be central to ensuring the protection of albatross and petrel populations (and marine ecosystems in general). On-board observer programs that use independent observers and include mandatory collection of by catch data will also be crucial in this process (Croxall and Nicol, 2004; Small, 2005), as will be a good understanding of the year-round distributions of the Southern Ocean's seabird populations.

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