AT-SEA DISTRIBUTION OF SATELLITE-TRACKED GREY-FACED PETRELS, *PTERODROMA MACROPTERA GOULDI*, CAPTURED ON THE RUAMAAHUA (ALDERMEN) ISLANDS, NEW ZEALAND

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(with three text-figures and five tables)

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We used satellite telemetry to determine the at-sea distribution of 32 adult (non-breeders and failed breeders) Grey-faced Petrels, *Pterodroma macroptera gouldi*, during July–October in 2006 and 2007. Adults captured at breeding colonies on the Ruamaahua (Aldermen) Islands ranged across the southwestern Pacific Ocean and Tasman Sea between 20–49°S and 142°E and 130°W. Petrels were located almost exclusively over offshore waters >1000 m depth. The extent of their distributions was similar across years, but petrels ranged farther south and west in 2006. Individuals displayed a high degree of spatial overlap (48–62% among individuals) and area use revealed three general "hotspots" within their overall range: waters near the Ruamaahua Islands; the central Tasman Sea; and the area surrounding the Chatham Rise. In July–August 2006, most petrels congregated over the Tasman Sea, but for the same period in 2007 were predominantly associated with Chatham Rise. The home ranges of petrels tended to overlap disproportionately more than expected with the Australian Exclusive Economic Zone and less than expected with High Seas, relative to the area available in each zone, in July–August 2006. Accordingly, multiple nations are responsible for determining potential impacts resulting from fisheries bycatch and potential resource competition with Grey-faced Petrels.

Key Words: satellite telemetry, utilisation distribution, home range, foraging range, Grey-faced Petrels, *Pterodroma macroptera gouldi*.

INTRODUCTION

Seabirds of the order Procellariiformes have evolved life history traits, behaviours and physiologies well-suited for coping with food resources that are patchily distributed over enormous (millions of square kilometres) pelagic habitats. Their ability to fast for extended periods and their extremely low cost-of-flight enables individuals to traverse large oceanic expanses while searching for patchily distributed food (Warham 1990, 1996). Our current knowledge about the distribution of gadfly petrels (*Pterodroma* spp.) at sea is limited to results from observations of birds from ships (Sladden & Falla 1928, Hyrenbach *et al.* 2006) and indirect measures of chick diet composition (Imber 1973). The relative importance of different oceanographic features and environmental conditions (e.g., bathymetry, ocean productivity, and wind speed) for determining gadfly petrel distributions at sea is not well known (but see Haney 1986, 1987, Stahl & Bartle 1991, Spear *et al.* 2001).

Detailed information about *Pterodroma* spp. ranges, migration routes, and habitat associations is required to understand environmental factors influencing species abundance and conservation issues. Increasing miniaturisation of tracking devices now enables continuous monitoring of small-bodied (<1000 g) procellariiform seabirds moving in remote and inaccessible areas of the ocean (e.g., Shaffer *et al.* 2006, Adams & Takekawa 2008). Tracking seabird movements can provide insights into patterns in range utilisation associated with elevated biological productivity ("hotspots"), significant biogeographical features such as oceanic current fronts, sea mounts, and sea-ice extent (Spear *et al.* 2001, Clarke *et al.* 2003, Morato *et al.* 2008), and intensively fished areas (Phillips *et al.* 2006). This information can be valuable for managers making decisions about species conservation or modifications to certain natural resource uses and developments within significant habitats (e.g., implementation of fisheries quotas and bycatch restrictions; Lewison *et al.* 2004). Awareness of hotspots will help managers prioritise their environmental management to times and places that are most important for species' persistence (i.e., critical foraging areas).

Our study focuses on the at-sea distribution of the Grey-faced Petrel, *Pterodroma macroptera gouldi* (Hutton, 1869), a culturally significant species to the northern *iwi* (Māori tribes), e.g., Hauraki, Ngāti Awa, Ngāti Wai) of New Zealand (B. Hughes pers. comm. 2006, T. Renata pers. comm. 2007, Lyver *et al.* 2008, T. Shortland pers. comm. 2008). The Grey-faced Petrel mainly breeds on islands off the east coast of northern New Zealand, with the largest colonies on the Ruamaahua (Aldermen), Moutohora (Whale) and Whakaari (White) islands (Wodzicki & Robertson 1959, Imber 1976, Heather & Robertson 2000). Populations of conspecific Great-winged Petrel, *Pterodroma macroptera macroptera* (A. Smith, 1840), nest on islands adjacent to the south coast of Western Australia, in the South Atlantic (e.g., Tristan de Cunha Group, Gough, Kerguelen and Crozet islands) and in the South Indian Ocean (e.g., Kermedec Islands; Warham 1956, Richardson 1984, Cuthbert & Sommer 2003). *Pterodroma m. gouldi* (and *P. m. macroptera*) are unique among the gadfly petrels as they are winter-time (Austral) breeders that lay eggs during June and July. Imber (1973) suggested that this phenology may be an adaptation to maximise nocturnal feeding time and more effectively exploit diel vertically migrating prey (e.g., various cephalopods and myctophid fishes). Observations of *P. macroptera* subspecies at sea indicate they rarely congregate in groups, except when resting on the sea surface during the day (Imber 1973, Hyrenbach *et al.* 2006). Historic accounts report that Grey-faced Petrels ranged mainly to the east of New Zealand between 31° and 42°S and about 150 km off the coast to 3200 km east (145°W) during the breeding season (Fleming 1950).

Here, we present the at-sea distribution patterns (i.e., movements) among individual Grey-faced Petrels captured during the breeding season at two breeding colonies on the Ruamaahua Islands during 2006 and 2007 and outfitted with satellite transmitters. The aims of our study were to determine: (a) the extent of the at-sea distribution of Grey-faced Petrels; (b) temporal variation in the degree of spatial overlap among individuals and the locations of high-use areas (hotspots); and (c) the extent and variability in the use of the New Zealand and Australian Exclusive Economic Zones (EEZs) versus the High Seas.

METHODS

Satellite telemetry

We attached satellite transmitters (Sirtrack Kiwisat 202 Platform Transmitter Terminals [PTTs], Havelock North, NZ) to 32 adults during two breeding seasons (2006 and 2007; table 1). Each year, we captured eight petrels at the colony during two periods: incubation (16–17 July 2006 and 19–20 July 2007) and early chick-rearing (12–13 September 2006 and 16–17 September 2007). In 2006, petrels were captured on the surface at two different locations (Locations 1, 2) on Ruamaahuanui in July and a single location (Location 3) on a neighbouring island, Hongiora, in September (fig.1, table 1). The reproductive status of the petrels in 2006 was, therefore, unknown because individuals captured were not associated with a burrow; petrels ultimately were classified as non-/failed breeders. In 2007 during the pre-laying period (April), we fitted 20 artificial nesting chambers (hereafter chambers) to existing burrows at a single location (Location 4) on Ruamaahuanui (fig. 1) to enable us to identify adult petrels of known breeding status. In July 2007, we captured eight incubating petrels from chambers and outfitted them with PTTs. In September 2007, only two chambers housed incubating petrels, so the remaining six adults were captured on the surface of the colony at night (similar to 2006) at Location 4 on Ruamaahuanui (fig. 1, table 1). Elsewhere, records indicate that most viable eggs hatch before 10 September (Bethells Beach breeding colonies; G. Taylor, pers. comm.). Thus, in 2007, we had eight confirmed breeders in July and two confirmed failed breeders and six petrels of unknown breeding status in September. We determined sex for 24 of the 32 individuals outfitted with PTTs using a DNA extraction technique adapted for feathers (Lambert *et al.* 2000).

We weighed petrels (±5 g) using a Pesola® spring scale (Pesola Ag, Baar, Switzerland) and fitted each with a uniquely numbered metal band. PTTs were affixed to

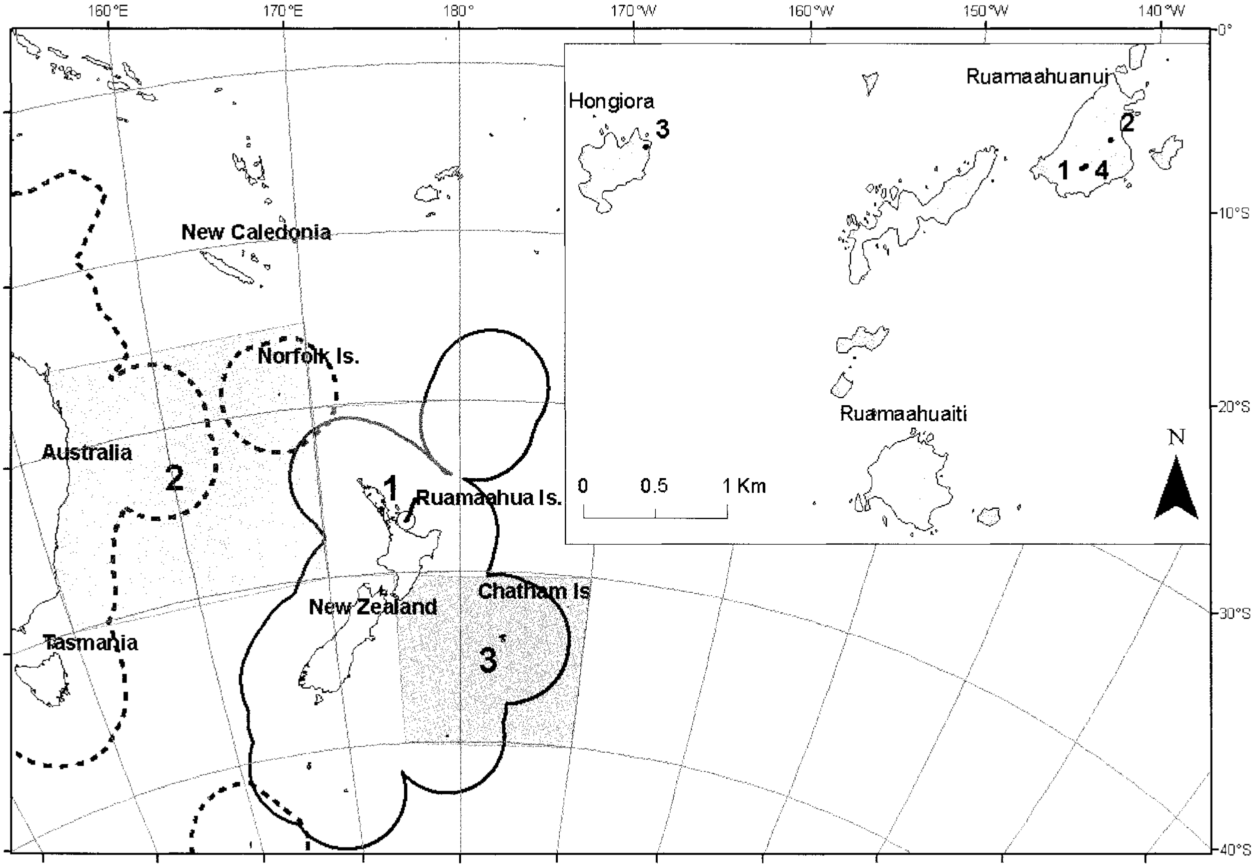

FIG. 1 — Key locations in the oceanic region surrounding New Zealand, including the location of the breeding colonies on the Ruamaahua Islands. A more detailed map of the Ruamaahua Islands is presented in the inset which shows the four locations where the birds were captured and released for satellite tracking. Solid black line indicates the New Zealand Exclusive Economic Zone and the dashed black line indicates the Australian Exclusive Economic Zone in the main figure and the three shaded boxes indicate the maximal extent of hotspots identified in the UD analysis (1 = Ruamaahua, 2 = Tasman, 3 = Chathams hotspots).

TABLE 1

Summary of the capture and satellite tracking data for 32 Grey-faced Petrels tagged at breeding colonies on the Ruamaahua Islands, New Zealand

Bird identity	Body mass (g)	Sex	Capture information				Days tracked	Locations retained	Distance travelled (km)	Latitudinal range		Longitudinal range		Home range area (km^2)		
			Island[1]	Location	Position	Date				North	South	East	West	25% contour	50% contour	95% contour
588	540	U	RN	2	Surface	16 Jul 2006	64	605	21,736	23.4°S	39.2°S	176.5°W	151.4°E	97,281	308,448	1,381,941
599	540	U	RN	1	Surface	16 Jul 2006	77	729	26,964	28.7°S	45.6°S	176.6°E	153.3°E	52,812	182,817	1,078,353
601	515	U	RN	1	Surface	16 Jul 2006	84	779	28,363	27.9°S	44.8°S	176.1°E	150.8°E	110,079	312,174	1,222,938
589	605	U	RN	2	Surface	17 Jul 2006	65	601	19,960	22.8°S	39.5°S	177.8°E	151.9°E	62,856	222,021	1,138,293
590	500	U	RN	2	Surface	17 Jul 2006	71	697	25,544	26.4°S	45.2°S	168.0°W	148.8°E	80,109	275,643	1,498,905
592	530	U	RN	2	Surface	17 Jul 2006	41	385	14,224	23.0°S	41.4°S	177.0°W	155.0°E	50,382	193,914	1,031,049
596	530	U	RN	2	Surface	17 Jul 2006	72	675	31,804	24.3°S	40.7°S	154.0°W	150.7°E	184,680	587,088	2,416,473
597	570	U	RN	2	Surface	17 Jul 2006	27	264	10,274	25.9°S	38.1°S	178.9°E	157.4°E	66,015	189,054	766,179
595	560	F	HA	3	Surface	12 Sep 2006	70	660	19,395	28.1°S	39.3°S	1797°E	151.0°E	39,690	117,936	656,181
598	520	F	HA	3	Surface	12 Sep 2006	39	407	13,669	29.8°S	43.2°S	158.1°W	156.9°E	70,632	212,058	955,962
600	630	F	HA	3	Surface	12 Sep 2006	40	413	19,934	26.2°S	48.7°S	166.4°W	160.3°E	116,559	368,388	1,571,967
602	575	M	HA	3	Surface	12 Sep 2006	17	170	7,117	26.7°S	38.4°S	177.4°E	151.7°E	36,450	125,388	533,061
591	530	F	HA	3	Surface	13 Sep 2006	40	393	20,475	19.6°S	41.8°S	130.6°W	162.7°E	98,820	314,604	1,508,949
593	550	M	HA	3	Surface	13 Sep 2006	26	285	12,704	24.9°S	40.4°S	168.6°W	153.5°E	89,748	263,331	1,036,233
594	550	M	HA	3	Surface	13 Sep 2006	22	180	7,420	31.2°S	43.1°S	166.4°W	176.0°E	45,927	135,027	554,202
603	590	M	HA	3	Surface	13 Sep 2006	82	794	26,211	30.9°S	47.8°S	176.9°E	144.1°E	42,525	115,830	601,830
605	570	M	RN	4	Burrow	19 Jul 2007	41	409	14,719	24.0°S	45.4°S	166.7°W	155.5°E	54,270	193,104	1,074,465
606	580	M	RN	4	Burrow[2]	19 Jul 2007	89	871	31,935	22.4°S	41.8°S	149.6°W	157.1°E	101,007	323,676	1,570,347
611	700	M	RN	4	Burrow	19 Jul 2007	49	480	19,119	26.2°S	46.4°S	158.2°W	158.1°E	78,975	269,811	1,347,111
614	585	M	RN	4	Burrow	19 Jul 2007	79	900	28,506	25.5°S	45.1°S	153.7°W	154.0°E	77,274	256,041	1,525,068
604	600	M	RN	4	Burrow	20 Jul 2007	88	989	35,869	31.4° S	48.9°S	168.6°W	160.9°E	121,257	379,728	1,734,615
607	545	M	RN	4	Burrow	20 Jul 2007	14	73	3,354	32.1°S	42.6°S	174.0°W	174.0°E	29,565	90,477	328,131
612	550	M	RN	4	Burrow	20 Jul 2007	96	997	38,163	30.7°S	47.9°S	139.3°W	141.5°E	117,045	366,363	1,885,923
613	550	M	RN	4	Burrow	20 Jul 2007	73	678	27,076	23.6°S	41.5°S	157.6°W	152.8°E	96,795	379,890	1,879,605
608	530	F	RN	4	Burrow	16 Sep 2007	20	237	10,110	25.1°S	41.4°S	152.0°W	176.1°E	78,489	244,458	925,344
609	535	M	RN	4	Surface	16 Sep 2007	34	381	13,050	31.5°S	37.2°S	172.0°W	156.6°E	49,086	146,610	657,234
610	500	F	RN	4	Surface	16 Sep 2007	20	238	7,496	28.4°S	37.0°S	177.1°E	160.5°E	26,406	89,181	431,487
615	525	F	RN	4	Burrow[2]	16 Sep 2007	8	91	2,088	29.3°S	37.0°S	178.4°E	167.6°E	11,988	37,827	196,668
616	540	F	RN	4	Surface	16 Sep 2007	36	424	11,330	30.7°S	38.6°S	177.5°E	158.8°E	28,836	79,866	442,422
617	535	F	RN	4	Surface	17 Sep 2007	17	188	5,827	28.1°S	36.9°S	176.8°E	160.5°E	27,540	81,243	407,997
618	545	F	RN	4	Surface	17 Sep 2007	46	542	18,586	22.6°S	40.8°S	130.3°W	174.5°E	78,813	247,374	1,232,982
619	525	F	RN	4	Surface	17 Sep 2007	76	861	18,986	27.3°S	37.0°S	177.0°E	150.7°E	45,036	128,952	586,278

[1] RN = Ruamaahuanui, HA = Hongiora, see fig. 1 for capture locations. [2] Indicates birds that were tagged from the same burrow.

petrels between the scapulae over the central synsacral area to be close to the petrel's centre of mass (Healy *et al.* 2004) using a suture-glue-tape method modified after Newman *et al.* (1999). Specifically, each PTT was attached using four sterilised, monofilament, polypropylene surgical sutures (CP Medical, PolyproTM 2-0), a single strip of tape (Tesa® AG 4657, Hamburg, Germany) underlying approximately four feathers, and a few drops of glue (TDS Loctite® 422, Henkel Technologies, Düsseldorf, Germany) between the base of the PTT and approximately four surface feathers. We opted for this attachment to maximise tag retention throughout the battery life of the transmitter (approximately 60 days). More importantly, the method provided a more stable attachment than tape alone and reduced the risk of the tag lifting and straining the feathers (and thereby altering the petrel's centre of mass) during normal flight, when the petrel rolled from side to side or pursued prey on the wing. An identical attachment has been successfully used with Sooty Shearwaters, *Puffinus griseus* (J.F. Gmelin, 1789), Greater Shearwaters, *Puffinus gravis* (O'Reilly, 1818), and Hawaiian Petrels, *Pterodroma sandwichensis* (Ridgway, 1884) (J. Adams unpubl. data). PTTs weighed 29–34 g (~5% of the mean mass among all petrels outfitted with PTTs; mean ± SE; 554.7 ± 7.1 g) and were 62 mm long × 26 mm wide × 17 mm high. PTTs were programmed to transmit signals with a 60-s repetition rate with 2-h "on:off" duty cycles to maximise transmission duration and the number of "high-quality" locations obtained during "on" periods.

Geographical locations of individual petrels were determined by ARGOS (CLS America 2007) and archived using the online Satellite Tracking and Analysis Tool (STAT; Coyne & Godley 2005). Prior to analysis we used the following procedure to filter potentially spurious locations provided by ARGOS. We retained all location classes (LC 3, 2, 1, 0, A, B) before filtering. For each satellite pass, ARGOS calculates two candidate PTT locations (i.e., "mirror locations" result from the intersection of two cones of satellite reception and the platform altitude ellipsoid) and specifies which location is the accurate one (CLS America 2007). Occasionally ARGOS will select the incorrect "mirror location" (i.e., <1% of total locations per individual; CLS America 2007). So we used STAT to identify potentially incorrect "mirror locations" in the raw data and manually swapped any incorrect mirror locations. Second, we applied a 0.001-h time filter with STAT to identify duplicate location records (i.e., two locations recorded at the same time). The less accurate (determined by the location classes provided by ARGOS) of the two duplicate records were then removed. Pre-filtered data were exported from STAT and read into Program R (version 2.6.1; R Development Core Team 2007). In R, we used the speed-distance-angle ARGOS filter (*SDAfilter* in the argosfilter package version 0.5; Freitas *et al.* 2008) with maximum ground speed threshold set to 60 km h^{-1} and default distance and angle threshold values. Filtered data then were read into MATLAB (MathWorks 2006) where we used purpose-built functions to create hourly, linear interpolated locations along each individual petrel's track-line (Tremblay *et al.* 2006). We did not interpolate track-line segments between endpoints separated by ≥8 h to avoid gross misrepresentation of an individual's actual position. Interpolation provided a temporally uniform distribution of locations for analyses that, unlike the raw ARGOS locations, are not biased by satellite orbital parameters and the petrel's latitudinal position (Georges *et al.* 1997, BirdLife International 2004).

Estimating utilisation distributions

To define the spatial probability distribution for each petrel, we calculated the fixed-kernel utilisation distribution (UD, Van Winkle 1975) for each individual's interpolated trackline using a raster composed of 9 × 9 km grid cells (81 km^2). This grid cell size was selected because 9 km is a conservative distance that encompasses the average accuracy of the combined ARGOS location classes. Nicholls *et al.* (2007) report a mean accuracy of <1 km for LC 3, 2, and 1 and <5 km for LC 0, A, and B. To calculate kernel values, we fitted a bivariate-normal model (using the kernelUD function, adehabitat v.1.7.1 package in R; Calenge 2006) and specified a conservative neighbourhood smoothing parameter of 27 km to best represent the actual tracks of individual petrels given the accuracy of the ARGOS locations (see Hyrenbach *et al.* 2002). All other parameters were set using the kernelUD default values. In this analysis, the home range of each individual was defined as the area within the 95% probability density contour (White & Garrott 1990; hereafter 95UD area). For clarity, "UD" alone refers to the fixed-kernel utilisation distribution (i.e., continuous probability surface composed of 9 × 9 km grid cells).

Estimating spatial overlap among individuals

To quantify spatial overlap among individuals within a given time period (i.e., two bimonthly periods [July–August and September–October] in each year), we calculated the percentage UD overlap of each petrel with all other individuals tracked during the same time period. Here we used the "PHR" method (Fieberg & Kochanny 2005) in the *kernel. overlap* function (Calenge 2006) to compute the probability of finding petrel *j* in the home range of animal i_1, i_2 etc., where the home range of each animal i_n was defined by its UD within its 95UD area. For each individual, we estimated the mean percentage UD overlap with all other individuals tracked during the same period. We considered this metric to be an informative, quantitative measure of the degree to which individuals within a population (i.e., the set of tracked petrels) share space in conjunction with the graphical analyses used to quantify hotspots (described below).

Comparative analysis of tracking and distribution parameters

We compared bimonthly (July–August and September–October) estimates of the number of days petrels were tracked, latitudinal and longitudinal range estimates and UD overlap among individuals in each year. For each of these variables, we fitted a linear mixed effects model (*lme* in R using the *nlme* package v. 3.1-86; Pinheiro & Bates 2000) with the following explanatory variables: "bimonthly period", "year", and the "bimonthly period × year" interaction. Where appropriate, we controlled for variation in sampling effort, by including the number of days that petrels were tracked in the model as a covariate. Because the same individuals were tracked in more than one bimonthly period, we included the petrels' unique PTT identities as a random effect in the model to control for repeated measures. We identified the minimum adequate model (i.e., determined whether or not to retain explanatory variables in the model) using a backward stepwise process. All percentage estimates of UD overlap were arcsin-transformed prior to analysis (Zar 1996). We also compared three parameter estimates (the number of days tracked, distance travelled and 95UD area) for males and females using unequal variance t-tests. All analyses were carried out using the statistical package, R (R Development Core Team 2007).

Quantifying hotspots of distribution at sea

For the purposes of our study, we define hotspots as those areas where the probability of locating an individual petrel (i.e., its UD) was high and where several individuals also visited the same location. To identify hotspots within a given bimonthly period in each year, we first summed the UD surfaces of the relevant individuals' 95UD areas (Σ_n 95UD). We then weighted the summed UD values for each 9 × 9 km grid cell according to the number of unique petrels that occupied it, using the formula: Σ_n 95UD/n_t^{-1}, where n_t was the number of unique individual 95UD areas which overlapped the grid cell. Thus, Σ_n 95UD/n_t^{-1} estimates for grid cells occupied by only a few petrels were down-weighted relative to those occupied by a greater number of petrels. To distinguish between areas with different probabilities of detecting occupancy by Grey-faced Petrels, we divided the weighted Σ_n 95UD esrimates into quartiles; the uppermost quartile indicated a very high probability of detecting occurrence and, therefore, the hotspots. For each bimonthly-year period, we also quantified the proportion of individuals that occupied the three main hotspots (fig. 1) and the proportion of the total area of individual 95UD areas that overlapped with each hotspot.

Quantifying use of Exclusive Economic Zones and High Seas

The EEZs for Australia and New Zealand include the oceanic waters extending to 200 nautical miles from each nation's mean low water mark. High Seas refer to those ocean areas outside a specific nation's EEZ. These waters and their resources are open to use by any nation, and do not belong to any nation. Rights and responsibilities for international use of the High Seas are defined under the United Nations Convention on the Law of the Sea (UNCLOS) to which both New Zealand and Australia are signatories (United Nations 2007).

We estimated the proportions of the individual 95UD areas within Australia and New Zealand's EEZ and High Seas. We then used compositional analysis (CA, Aebischer *et al.* 1993) to determine whether or not the 95UD areas were randomly located with respect to these zones. To do this, we identified the area of each zone potentially available (i.e., "available area") for each petrel. We assumed that the available area for each petrel was all oceanic habitat within an area defined by a radius equivalent to the maximum straight-line distance between each petrel's initial location record and all other location records obtained for that petrel within the relevant bimonthly-year time period. The initial location may have been either on the Ruamaahua Islands or at sea, depending on the time period considered. We then calculated the proportion of each petrel's available area that intersected with each zone. To determine whether petrels were disproportionately located within one zone versus another, we compared the relative proportion of the available area within each zone to the relative proportions of the 95UD areas (i.e., "used areas") within each zone. Our CA used the randomisation test in the *compana* function (Calenge 2006). All other parameters (the number of replicates, zero replacement values, and alpha thresholds) were set using the default values.

RESULTS

Satellite tracking

Individual Grey-faced Petrels were tracked for (mean ± SE) 51 ± 5 days (range: 8–96) and PTTs generated 10 ± 0.2 usable (i.e., post-filtered) locations per day (table 1). On average, individuals travelled 18 500 ± 1697 km (range: 2088–38 160) and had home ranges (95UD areas) which covered 1 068 000 ± 94 833 km^2. Core use areas (as indicated by the 25% and 50% UD area contours) covered 70 840 ± 6476 and 226 200 ± 20 942 km^2 respectively (table 1).

All petrels tagged early in the breeding season (July) were males (feather samples were only available for 2007). The sex composition of petrels tagged in September varied between years (in 2006: four males, four females; 2007: one male, seven females; table 1). Males were tracked for a slightly longer duration (males vs females; 55 ± 9 vs 38 ± 6 days), tended to travel farther (20 403 ± 3217 vs 13 445 ± 1959 km) and have larger home ranges (1 132 910 ± 154 860 vs 810 567 ± 140 535 km^2), but none of these trends was statistically significant (Unequal variance t-tests; Days: t = -1.61, d.f. = 21.3; P = 0.122; Distance: t = -1.85, d.f. = 19.4; P = 0.08; Area: t = -1.54, d.f. = 22.0, P = 0.140).

Colony attendance and breeding status

Five of 32 (16%) Grey-faced Petrels returned to the colony at least once (table 2). The flight path of one additional petrel (bird identity: 594) indicated that it likely also returned to the colony (absence of location data during the following 24-hour period upon near arrival prevented confirmation, but this pattern is consistent with the inability of satellites to receive signals when petrels are underground (J. Adams unpubl. data)). The number of individuals that returned to the colony varied between observation periods. Two of the eight petrels tagged in each July returned to the colony, but during September, only one returned in 2006 and none in 2007 (table 2). Patterns of colony attendance also varied among the five petrels that returned to the colony. All, except one (bird identity: 596), returned to the colony only once. Petrel 596 completed four trips over a five-day period with each trip lasting 1–3 days and covering 69–1244 km (table 2). The average duration of the trips undertaken by the remaining four petrels was 33 ± 6 days, during which they travelled an average total distance of 14 430 ± 2743 km and maximum straight-line distance from the colony of 996 ± 343 km (range: 41–2587). For petrels that returned to the colony, the mean number of outward- and inward-bound flights observed per individual was 3 ± 1 and 2 ± 1 respectively. Of the 11 artificial nesting chambers that had eggs during July 2007, none had chicks in September, indicating that all breeding attempts initiated in these chambers were unsuccessful, irrespective of whether the breeding petrels were tagged or not.

At-sea distribution

Grey-faced Petrels tracked during the breeding season (July–December) covered a wide geographical range (table 1; latitudinal range: 19.6–48.9°S; longitudinal range: 141.5°E–130.3°W). In both years, a few individuals travelled north towards New Caledonia or east to the Kermadec Trench or beyond. During September–October each year, one or two petrels travelled as far south as Tasmania, travelling along the east coast of the island to its southern-most

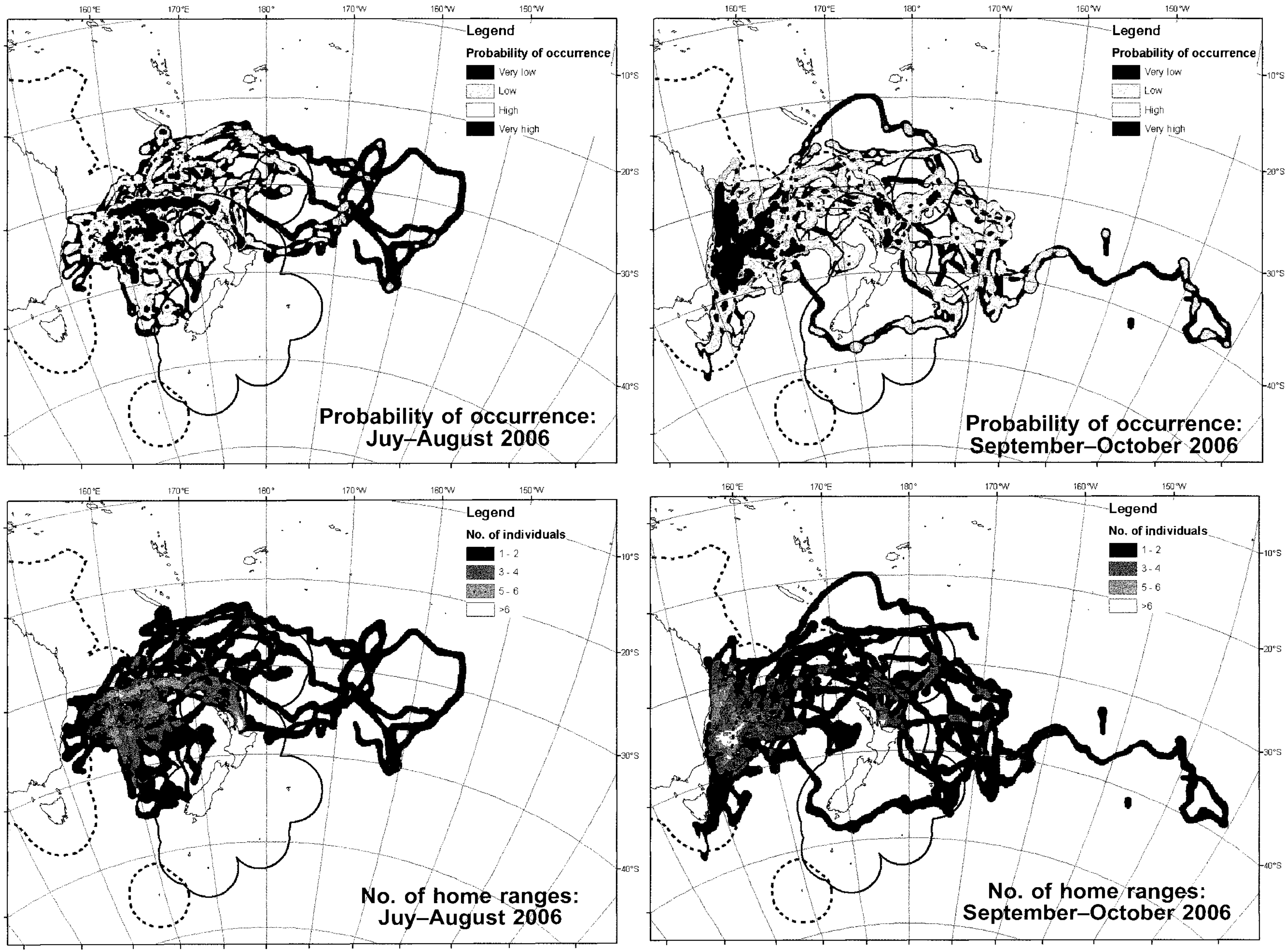

FIG. 2 — At-sea distribution of satellite-tracked Grey-faced Petrels from the Ruamaahua Islands, New Zealand. Each shows the probability of occurrence and the number of home ranges which overlapped each 9 x 9 km grid cell within a given bimonthly period and year. Solid black line indicates the New Zealand Exclusive Economic Zone and the dashed black line indicates the Australian Exclusive Economic Zone.

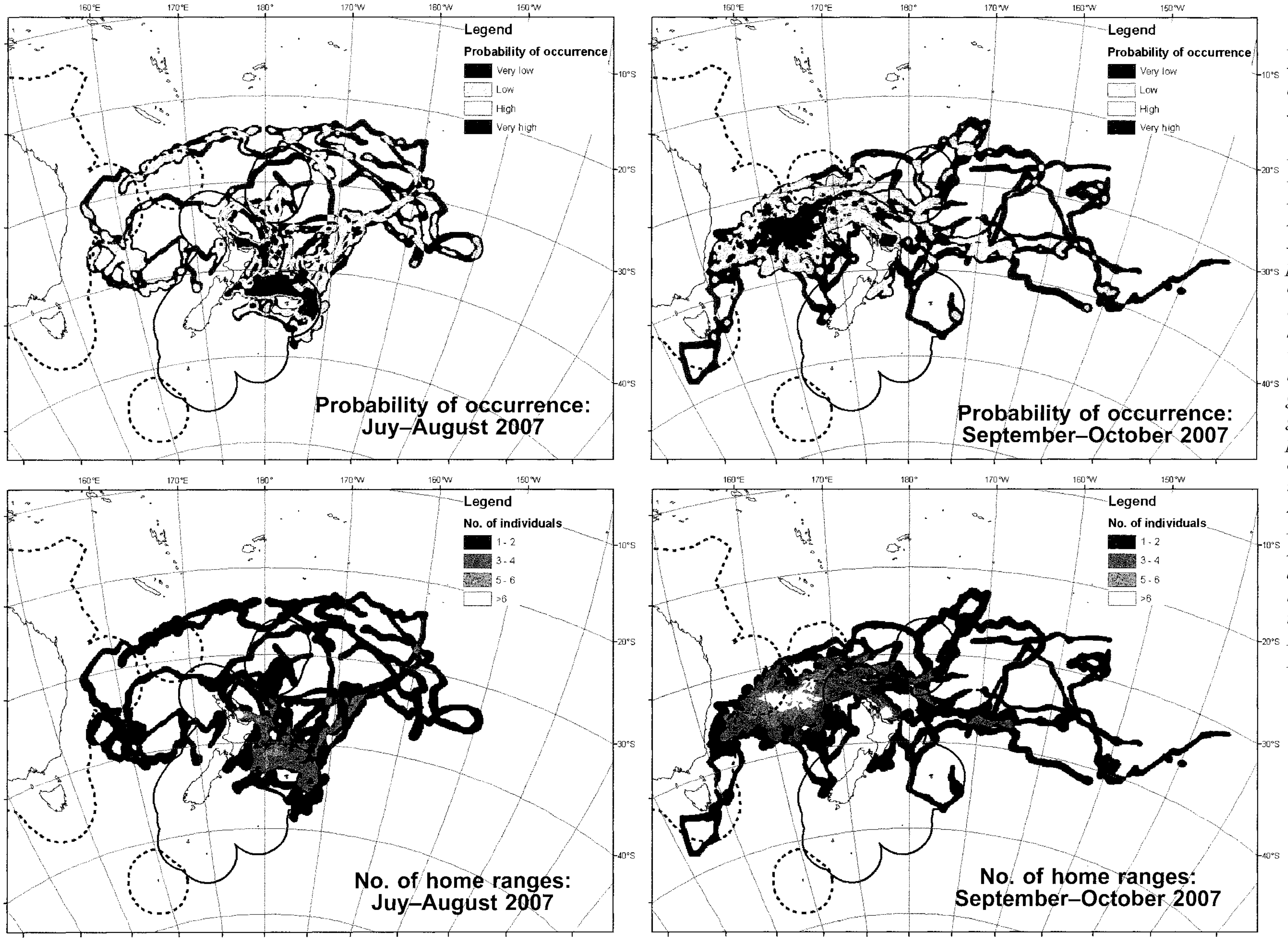

FIG. 2 continued — At-sea distribution of satellite-tracked Grey-faced Petrels from the Ruamaahua Islands, New Zealand. Each shows the probability of occurrence and the number of home ranges which overlapped each 9 x 9 km grid cell within a given bimonthly period and year. Solid black line indicates the New Zealand Exclusive Economic Zone and the dashed black line indicates the Australian Exclusive Economic Zone.

TABLE 2
Summary of foraging trip information for satellite-tracked Grey-faced Petrels that returned to the colony at least once

Bird identity	Trip identity	Date start	Trip duration (days)	Return to colony	Distance travelled (km)	Maximum distance from colony (km)
588	1	16 Jul2006	23	Y	9,339	1,681
	2	8 Aug 2006	41	N	13,347	2,257
596	1	17 Jul 2006	3	Y	1,244	494
	2	20 Jul 2006	1	Y	69	41
	3	21 Jul 2006	1	Y	86	41
	4	22 Jul 2006	1	Y	83	42
	5	23 Jul 2006	66	N	31,189	2,991
600	1	12 Sep 2006	23	Y	11,003	1,556
	2	5 Oct2006	17	N	9,796	1,681
604	1	24 Jul 2007	48	Y	21,547	1,524
	2	10 Sep 2007	36	N	16,358	1,415
611	1	31 Jul 2007	37	Y	15,830	2,587
	2	6 Sep 2007	12	N	4,111	1,589

All Grey-faced Petrels were originally captured on the Ruamaahua Islands' breeding colonies (see table 1 for details).

point, before heading north again. However, most petrels congregated within the Tasman Sea between 30 and 40°S (i.e., within the High Seas between Australia and New Zealand; fig. 2).

Although the extent of the Grey-faced Petrel geographical range was similar between years, there was notable temporal variation. Individual tracking durations varied between bimonthly and yearly periods (table 3). After controlling for the variation in tracking duration (i.e., number of days) between periods, the southern latitudinal extent was consistent across years for the July–August period, but varied between years in the September–October period, with petrels travelling farther south in 2006 than in 2007 (table 3). Grey-faced Petrels also ranged farther west in 2006 than in 2007, when individuals travelled parallel to the edge of the southeast Australian continental shelf, and later in the season in both years. There was no evidence of a significant shift in the northern extent of their distribution, but there was a trend for petrels to travel farther east in 2007, when a greater proportion congregated around the Chatham Rise (fig. 2).

Spatial overlap and hotspots of distribution at sea

Grey-faced Petrels occurred primarily over waters >1000 m deep (mean ± SE; 93 ± 2% of the 95UD areas; n = 32) rather than over continental-slope (200–1000 m: 6 ± 2%) or continental-shelf waters (<200 m: <2%). Estimates of spatial overlap among petrels within bimonthly periods varied between years (July–August: 62 ± 4% in 2006, 49 ± 9% in 2007; September–October: 55 ± 7% in 2006, 48 ± 7% in 2007), but were not statistically significant ($P >$ 0.10).

Greatest weighted Σ_n 95UD values were located primarily between 30–45°S, where we identified three main hotspots of Grey-faced Petrel distribution at sea (fig. 2): (1) the "Ruamaahua hotspot" included the region centred on the breeding colonies on the Ruamaahua Islands; (2) the predominant "Tasman hotspot" was located in the Tasman Sea; and (3) the "Chatham hotspot" was centred on the Chatham Rise. Other smaller hotspots also were detected in the vicinity of the Kermadec–Tonga trenches and Norfolk Island (fig. 2).

The extent and location of the Ruamaahua hotspot displayed spatio-temporal variability. In the July–August period, it extended from the Ruamaahua Islands approximately parallel to the northern coastline of New Zealand's North Island, in a northwesterly direction in 2006 and in an easterly direction in 2007 (fig. 2). The fact that all individuals were observed in the Ruamaahua hotspot during the July–August period in each year reflects departure and arrivals after being captured at the colony (table 4). A lower proportion of individuals (64–93%) was recorded within this hotspot during the September–October periods (fig. 1) because most of the individuals captured in July did not return to the colony during this period (tables 2, 4). The mean percentage area of individual home ranges overlapping the Ruamaahua hotspot ranged between 10 and 18% (fig. 1, table 4).

The location and extent of the Tasman hotspot also displayed spatio-temporal variability. In 2006, the Tasman hotspot extended from approximately 170–155°E and from 30–40°S during the July–August period (fig. 2), but then shifted approximately 5° west during the September–August period. During the latter period, the hotspot paralleled the east coast of Australia from 28–42°S (fig. 2). In 2007, this hotspot was absent in the July–August period (fig. 2), but was present in the September–October period (fig. 2), when it was smaller and centred towards the middle of the Tasman Sea between 155–170°E and 30–38°S. A greater proportion of individuals (86–100%) visited the Tasman hotspot (fig. 1) among all periods, except in July–August 2007 when only 38% of individuals were recorded there (table 4, fig. 2). On average, >50% of each Grey-faced Petrel's total home range area overlapped with the Tasman hotspot, except in July–August 2007 when this was reduced to 13% (table 4).

TABLE 3
Summary of the extent of at-sea distribution data for satellite-tracked Grey-faced Petrels in each bimonthly period in each year.

Variable	July–August		September–October		Year effect			Bimonthly effect			Bimonthly × year effect		
	2006 (n = 8)	2007 (n = 8)	2006 (n = 14)	2007 (n = 14)	*F*	d.f.	*P*	*F*	d.f.	*P*	*F*	d.f.	*P*
Days tracked	42.9 ± 2.4	36.3 ± 3.5	30.9 ± 3.0	32.6 ± 3.7	0.43	1,30	0.51	13.97	1,10	0.004	9.99	1,10	0.01
North	25.6 ± 1.0 °S	28.1 ± 1.6°S	27.6 ± 0.9°S	28.6 ± 0.7°S									
South	41.3 ± 1.1°S	44.2 ± 0.9°S	41.5 ± 1.0°S	39.9 ± 1.0°S	0.003	1,30	0.96	1.65	1,9	0.23	6.92	1,9	0.03
East	154.9 ± 1.2°W	167.7 ± 3.2°W	154.7 ± 2.1°W	159.3 ± 2.4°W	3.67	1,30	0.06						
West	175.8 ± 3.6°E	166.1 ± 3.7°E	177.8 ± 5.2°E	170.6 ± 4.8°E	8.01	1,30	0.008	12.77	1,10	0.005			

All Grey-faced Petrels were originally captured on the Ruamaahua Islands' breeding colonies (see table 1 for details). Linear mixed effects models were used to test for temporal variation, the Minimum Adequate Models are presented for those where P < 0.1.

TABLE 4
Percentage of individuals and the average percentage of individual total 95UD areas which overlapped with three different hotspots (Ruamaahua, Tasman and Chathams) versus other oceanic areas for each bimonthly-year period

Variable	Oceanic area	July–August		September–October	
		2006 (n = 8)	2007 (n = 8)	2006 (n = 14)	2007 (n = 14)
Percentage of tagged birds visited area	Ruamaahua hotspot	100	100	64	93
	Tasman hotspot	100	38	93	86
	Chathams hotspot	0	88	21	14
	Other areas	100	100	79	79
Percentage of home range area	Ruamaahua hotspot	14 ± 3	15 ± 4	10 ± 2	18 ± 4
	Tasman hotspot	55 ± 7	13 ± 8	61 ± 9	55 ± 8
	Chathams hotspot	0 ± 0	28 ± 9	3 ± 2	2 ± 1
	Other areas	31 ± 7	45 ± 9	26 ± 7	25 ± 8

All Grey-faced Petrels were originally captured on the Ruamaahua Islands' breeding colonies (see table 1 for details).

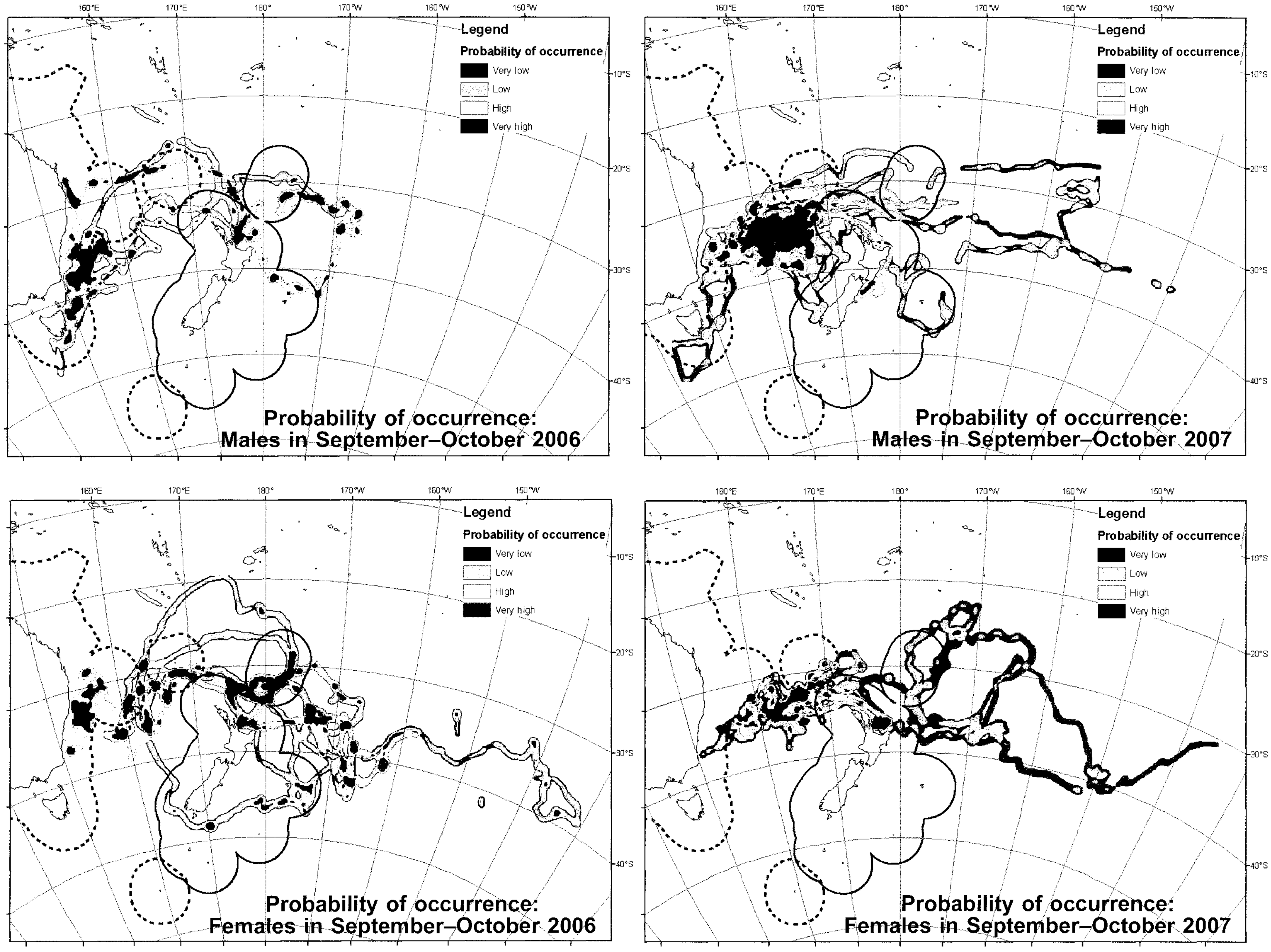

FIG. 3 — At-sea distribution of satellite-tracked Grey-faced Petrels from the Ruamaahua Islands, New Zealand for males and females in September–October in 2006 and 2007. Maps show the probability of occurrence (2006: n_{males} = 4, $n_{females}$ = 4, 2007: n_{males} = 7, $n_{females}$ = 7). Solid black line indicates the New Zealand Exclusive Economic Zone and the dashed black line indicates the Australian Exclusive Economic Zone.

The Chathams hotspot only was detected in July–August 2007, when 88% of Grey-faced Petrel individuals travelled to this region. In both years, a small proportion of individuals (14–21%) visited the Chathams hotspot in the September–October period (table 4, figs 1, 2). On average, approximately 28% of each Grey-faced Petrel's total home range area overlapped with the Chathams hotspot in July–August 2007, compared with <4% for all other periods (table 4, figs 1, 2).

Only a small proportion of individuals visited both Tasman and Chatham hotspots (July–Augusr 2006, 0%; July–August 2007, 25%; September–October 2006 & 2007, 14%).

A comparison of the distribution of males and females during the September–October periods (fig. 3) shows both males and females congregated over the Tasman hotspot in both years, with males tending to travel farther west and south than females. In contrast, females tended to travel farther to the east and north of the Ruamaahua Islands in both years, but particularly in 2006, when hotspots of distribution were observed between the Kermedec Trench and the Chatham Rise.

Use of Exclusive Economic Zones and High Seas by Grey-faced Petrels

Within each bimonthly-year period, the home ranges among all tracked petrels overlapped the High Seas and New Zealand EEZ, except in September–October 2006 when only 71% of home ranges overlapped with New Zealand's EEZ (table 5). The proportions of home ranges that overlapped the Australian EEZ were more variable, ranging from 38% in July–August 2007 to 100% in July–August 2006 (table 5). The average proportion of an individual's 95UD area which overlapped with each zone also varied (High Seas: 38–52%; New Zealand EEZ: 20–49%; Australia EEZ: 5–46%) during the same four bimonthly-year periods (table 5).

After taking into account the relative area available to individuals within each zone, CA revealed no evidence indicating differential use of particular zones during the bimonthly-year periods considered, except in July–August 2006 (table 5). Grey-faced Petrel 95UD areas tended to overlap disproportionately more than expected with the Australian EEZ and less than expected with High Seas during July–August 2006 only. Because zero replacement data can increase the likelihood of a Type-I error in CA (Bingham & Brennan 2004), we evaluated *P* values and the number of zero replacements for each bimonthly-year comparison. The average percentage of individuals with zero utilization values per zone in any given bimonthly-year period was <30% (table 5), and for the only comparison with a significant *P*-value (July–August 2006), there were no zero replacements.

DISCUSSION

Satellite tracking

Most satellite telemetry studies investigating the movements of far-ranging pelagic seabirds have involved large-bodied seabirds (>1000 g), with the vast majority of studies targeting adult breeding birds (BirdLife International 2004). As PTTs become smaller and new attachment methods are developed, we anticipate an increase in the use of this technology applied to the much smaller (<1000 g) seabirds including other gadfly petrels (Burger & Shaffer 2008). Although Phillips *et al.* (2003) recognise that PTT deployments on petrels and albatrosses can increase nest desertion and increase foraging trip durations, they suggest that tracking data derived from birds carrying PTTs remains representative of species' foraging areas (see also Ackerman *et al.* 2004, and Wilson *et al.* 2002). We acknowledge that PTTs used in this study (~5% adult body mass) are above the recommended ~3% value suggested by Phillips *et al.* (2003). We do not have the required data to determine if nest desertion among incubating petrels (n = 8 captured in July 2007) observed in this study resulted from handling during the incubation period, detrimental effects of PTTs, or a combination of both factors. Although at least 16% of the 32 tagged petrels returned to the colony at least once, most of which were captured in July during incubation, normal colony attendance patterns for individual breeders on the Ruamaahua Islands during the breeding season remains poorly understood (but see Imber (1976) for information gathered from burrow surveys on Moutohora Island). Due to breeding failures and the tagging of non-/failed breeding individuals, the 2006 and 2007 tracks primarily quantify the movements of individuals free to roam with fewer constraints imposed by the need to return to their colony (as might be expected among adults provisioning chicks at regular intervals). Yet, the degree to which movements of the tagged petrels were affected by the attached tags remains unknown. Provided there are no techno-environmental constraints (i.e., functionality of lightweight solar-powered PTTs deployed in regions with greater cloud cover), future satellite telemetry studies investigating gadfly petrel movements should aim for deployments involving smaller transmitters whenever possible.

At-sea distribution

Our results indicate that Grey-faced Petrels from the Ruamaahua Islands are confined to the southwestern portion of South Pacific subtropical gyre and the Tasman Sea. This is the first study to describe the at-sea distribution of non-breeding (including failed incubating) Grey-faced Petrels during the breeding season (July–December). Although the movements of the petrels may have been affected by using PTTs, our results are consistent with previous at-sea observations from ships that indicate that the Grey-faced Petrel and its conspecific, *P. m. macroptera*, are restricted to the southern subtropical gyres of the Pacific, Indian and Atlantic oceans (Sladden & Falla 1928, Fleming 1950, Imber 1973). Historical accounts report Grey-faced Petrels were common about 200 miles from the coast of New Zealand to the north and east (Sladden & Falla 1928) and were regularly seen northwards to the Kermadec Islands (30°S; Imber 1973). Our satellite tracking data show that individuals travelled predominantly towards the west of New Zealand into the Tasman Sea. The opposite was reported by Fleming (1950) who suggested that during the breeding season, Grey-faced Petrels range mainly to the east of New Zealand between 31° and 42°S and about 150 km off the coast to 3200 km east (145°W). Based on observations at Moutohora (Whale Island), including stomach contents of chicks, Imber (1973) deduced that breeding Grey-faced Petrels probably forage primarily beyond the continental shelf and, similar to Fleming (1950), he suggested that individuals foraged at least 500 km southeastwards towards the Subtropical Convergence. Imber (1973) also suggested that non-breeders are not likely to be

TABLE 5

Bimonthly-year estimates of the percentage of individuals with available area and home ranges (95% UD areas) that overlapped each zone and the mean (± SE) percentage of areas available and 95UD areas within New Zealand and Australian Exclusive Economic Zones (EEZ) and High Seas for Grey-faced Petrels from the Ruamaahua Islands' breeding colonies

Variable	Zone	July–August		September–October	
		2006 (n = 8)	2007 (n = 8)	2006 (n = 14)	2007 (n = 14)
Percentage of individuals with available areas in region	High Seas	100	100	100	100
	New Zealand EEZ	100	100	86	100
	Australia EEZ	100	100	100	100
Percentage of home ranges overlapping each region	High Seas	100	100	100	100
	New Zealand EEZ	100	100	71	100
	Australia EEZ	100	38	93	86
Percentage of total available areas	High Seas	69 ± 1	67 ± 3	64 ± 4	70 ± 3
(Mean ± SE)	New Zealand EEZ	24 ± 2	26 ± 4	15 ± 3	21 ± 3
	Australia EEZ	8 ± 1	7 ± 1	21 ± 6	9 ± 3
Percentage of total home range area	High Seas	52 ± 5	46 ± 9	38 ± 5	48 ± 6
(Mean ± SE)	New Zealand EEZ	20 ± 3	49 ± 10	17 ± 5	27 ± 5
	Australia EEZ	28 ± 5	5 ± 2	46 ± 8	25 ± 5
Rank[1]	High Seas	3	2	2	3
	New Zealand EEZ	2	1	3	2
	Australia EEZ	1	3	1	1
Compositional analysis	λ	0.253	0.371	0.801	0.846
	P	0.046	0.094	0.362	0.408

Compositional analysis was used to test for whether, relative to an individual's available area in each zone, the home ranges overlapped disproportionately with specific zones.

[1] Relative use of zones was ranked where 1 = high use relative to available areas and 3 = low use relative to available areas, based on compositional analysis.

as constrained as breeders by the need to return regularly to their colony, so they can range farther from colonies (but see, Stahl & Sagar (2006) regarding non-breeder movements in an albatross). Currently, it is not known whether petrels affiliated with Moutohora have a different distribution at sea. Consistent with suggestions by Imber (1973), Grey-faced Petrels tracked from the Ruamaahua Islands occurred predominantly (>90% of time at sea) over deep (>1000 m) offshore waters. This affiliation for pelagic waters also is consistent with observations from summer (January) surveys in the southern Indian Ocean, where *P. m. macroptera* dominated the deep-water offshore avifauna north of the Subtropical Convergence between ~30 and 38°S, albeit at low densities (<1 bird km^{-2}; Hyrenbach *et al.* 2007). Together these results indicate that Grey-faced Petrel conspecifics are probably affiliated with subtropical pelagic areas throughout the year.

Oceanographic setting structuring Grey-faced Petrel distributions

At the mega-scale (i.e., the entire breeding season range among non-/failed breeders), sea surface temperatures range from 4–28°C in the region occupied by Grey-faced Petrels (Ridgway *et al.* 2002, MacLeod *et al.* unpubl. data). Winter (July through September) productivity (mean surface chlorophyll concentrations), especially northeast of New Zealand and in the north-central Tasman Sea, is greater than in surrounding waters (Gregg & Conkright 2001, MacLeod *et al.* unpubl. data). Elsewhere, oceanic boundaries and fronts also have been shown to influence the distribution and abundance of seabirds. For example, Spear *et al.* (2001) described the importance of temperature gradients and vertical hydrography in structuring pelagic seabird communities in the tropical Pacific. They show that piscivorous seabird densities (e.g., Juan Fernandez Petrel *Pterodroma externa* (Salvin, 1875)) were more strongly influenced by the depth and intensity of the thermocline than the location of the Equatorial Front. They suggest that avian piscivore densities were greatest where the thermocline was deepest and most stratified, because this is where their prey were presumably most concentrated.

Individual petrels tracked from the Ruamaahua Islands aggregated within areas defined by well-described, semi-permanent oceanographic circulation features, including (1) the Subtropical Front (STF) centred over the Chatham Rise, (2) the East Auckland Current, (3) the Tasman Front, and (4) the East Australian Current (EAC; Chiswell &

Rickard 2006, Roemmich & Sutton 1998, Ridgway *et al.* 2002). The locations of these features are constrained by the underlying basin, ridge and plateau bathymetry (Chiswell & Rickard 2006). Furthermore, the EAC separation zone (i.e., the region where the EAC splits into two parts: the Tasman Outflow and the Tasman Front) is characterised by large-scale turbulence, which spawns numerous cyclonic and anti-cyclonic eddies, the largest and strongest of which occur near the coast, south of 32° (Nilsson & Cresswell 1981, Mata *et al.* 2006). Although the importance of these features to Grey-faced Petrels remains unknown, we currently are examining how eddy fields are associated with strong physical and chemical gradients known to enhance biological production of potential micronekton (Lutjeharms *et al.* 1985) and cephalopod (Lansdell & Young 2007) prey. These features may indeed be important habitat for foraging Grey-Faced Petrels.

Spatial overlap and hotspots of distribution at sea

The degree to which the kernel-based UDs within individual's home ranges (i.e., 95UD areas) overlap provides unique information about space-use-sharing throughout the sample population's large range at sea. We found a seemingly high degree of overlap (mean range: 48–62%) among Grey-faced Petrels' home ranges. Somewhat contrary to our finding, observations of Grey-faced Petrels at sea indicate they rarely congregate in groups, except when resting on the sea surface during the day (Imber 1973, Hyrenbach *et al.* 2006). Variation in spatial overlap, however, is currently not well understood but could reflect individual variability in searching strategies and foraging destinations (i.e., including breeders vs. non-breeders), inter-annual differences in weather or oceanographic conditions, or changes in the distribution or availability of key prey resources. These data indicate that among Grey-faced Petrels attending the breeding colonies on the Ruamaahua Islands, individuals appear to occupy similar areas within their vast range at sea during the Austral winter and spring. Furthermore, the tendency for individuals to overlap within certain areas at sea, allowed us to better identify several key hotspot areas.

Our study identified three hotspots for Grey-faced Petrel distribution at sea: the Ruamaahua, Tasman and Chatham hotspots. The Ruamaahua hotspot was centred, as expected, on the Ruamaahua Islands, the location of the breeding colonies and the deployment site for the tracked petrels. This hotspot appears to encompass the predominant flight paths used by the petrels heading away from the colonies along the coast of the North Island of New Zealand. The slight shift in proximity of this hotspot between years may reflect differences in the wind and oceanic conditions in each season. The extent and location of the Tasman hotspot also varied between years and bimonthly periods, which may be related to temporal shifts in the location and intensity of the EAC and the associated Tasman Front. Expected inter-annual variability in the oceanography and local variations in marine productivity may help explain the shift in the extent and location of the Tasman hotspot, and perhaps the emergence of the Chatham hotspot in 2007. There also exists the possibility that the Chatham hotspot identified in July–August 2007, resulted from differences in the movements and subsequent distribution among breeding petrels captured within nesting chambers. This indicates that breeders and non-breeders may occupy different regions at sea, potentially to avoid interference competition. A similar pattern has recently been observed among non-/failed breeding vs chick-provisioning Hawaiian Petrels outfitted with PTTs (J. Adams & D. G. Ainley unpubl. data). A more detailed investigation that incorporates oceanography and satellite-derived locations among Grey-faced Petrels will provide a better understanding of the importance of oceanographic features that influence the location of the hotspots areas.

The location of these hotspots also may be influenced by key geographic features in the cooler, more productive waters of the Tasman Sea, where predatory fish species such as tunas (e.g., *Thunnus maccoyii* Castelnau, 1872) and swordfishes (e.g., *Xiphias gladius* Linnaeus, 1758) are known to feed (Young *et al.* 1996, 2006). Grey-faced Petrels are thought to rely, in part, on these subsurface predators to locate and flush prey to the ocean surface. Swordfish, for example, feed over the Tasman Seamounr and Lord Howe Rise, which are flushed by the colder, more productive subantarctic waters and support increased prey biomass (Campbell 2002, Young 2004).

Documentation of at-sea hotspots for Grey-faced Petrel distribution in the Tasman Sea and near the Chatham Islands has important implications in the wake of potential climate change impacts to this region. Climate modelling indicates that changes in the Southern Annular Mode (SAM), the dominant mode of variability in the southern hemisphere atmospheric circulation, could cause dramatic climate-induced change especially to the EAC, but also in the southwestern Pacific (Cai *et al.* 2005). Predicted changes in the near future (50–100 yrs) include an increase in wind-stress-curl east of the Chatham Islands, and warming and strengthening of the EAC (Cai *et al.* 2005). Predicting the effects of these changes on Grey-faced Petrel distribution and foraging ranges requires a more detailed understanding of the importance of these different oceanographic and climatic conditions in determining their movement patterns.

Implications for multinational ocean management

Determining the spatial and temporal patterns in the at-sea distribution of Grey-faced Petrels is important from a management perspective. Effective conservation and management for extremely mobile and far-ranging marine vertebrates depends increasingly on multinational efforts (Lewison *et al.* 2004), especially when target organisms transverse geopolitical boundaries (e.g., BirdLife International 2004). In a first effort to identify nations that oversee marine resources which provide important habitat for Grey-faced Petrels breeding on the Ruamaahua Islands, New Zealand, we measured habitat use among individuals that occupied three geopolitical marine zones: New Zealand's EEZ, Australia's EEZ, and the area within the petrel's range intersecting the High Seas. At least a third of the area within each Grey-faced Petrel's home range overlapped with the High Seas jurisdictional zone, with the remaining area split, to varying degrees, between the New Zealand and Australian EEZs. Whereas New Zealand entities (iwi, the Ministry for Fisheries and the Department of Conservation) oversee protection, conservation and management for Grey-faced Petrels and other seabirds in their jurisdictional region, jurisdiction over the High Seas in the Tasman Sea and southwestern Pacific Ocean is shared by the Western and Central Pacific Fisheries Convention (WCPFC) nations (BirdLife International 2004).

Because gadfly petrels often feed in association with subsurface predators, some species are at risk from certain industrialised fishing practices (such as longlining) that target these fishes. Furthermore, many gadfly petrels scavenge food from the surface, including baited hooks, and other procellariid seabirds potentially are attracted to or disoriented by artificial light sources at sea (Reed *et al.* 1985). Multinational fishing operations targeting pelagic fishes such as tunas and billfishes operate to varying degrees in waters used by Grey-faced Petrels. Although many of these fisheries are increasingly adopting measures to reduce seabird bycatch, observer coverage among many fisheries is insufficient to assess accurately the impact of fisheries activity on procellariiform seabird populations (Lewison *et al.* 2004).

We have made preliminary progress by identifying key use areas for Grey-Faced Petrels. Future studies should aim to investigate the extent of overlap between the at-sea distribution of Grey-faced Petrels (of known breeding status if possible) and commercial fisheries activity to determine the risk that this industry poses for this species. Research should also determine the environmental factors influencing the at-sea distribution of Grey-faced Petrels to provide a better understanding of the potential impact of climate change. Without this information, resource managers would be unable to assess (1) direct and indirect effects of commercial fisheries, or (2) the effect of oceanic and atmospheric climate on Grey-faced Petrel population dynamics (i.e., survival, abundance).

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