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A population and distributional study of white-capped albatross (Auckland Islands)

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Abstract

White-capped albatross is the most numerous albatross species breeding in New Zealand, but is also the most frequently returned from commercial fishing operations. A study population was established on a slope free from feral pig activity. The study population comprised about 70 nests that were used at some time over the course of the project. All but 12 breeding adults using these nests were captured and fitted with a uniquely numbered metal leg band. Re-sighting data and breeding frequency data were modelled using SeaBird which estimated adult survival to be 0.96, and the probability that a bird that bred in one year would also breed in the next year to be 0.63, whereas the probability that a bird that didn't breed in one year but which would breed in the next year was 0.78. These results, together with observational data of birds breeding in successive years indicate that white-capped albatross has a breeding strategy intermediate between annual and biennial.

At-sea distributions were determined using three complementary tracking technologies. GPS tags were deployed in order to gather fine-scale, high resoution albatross location data with which to compare with similar data from commercial fishing operations. A novel approach to combining these two data sets was established in order to quantify fine-scale overlap between individual seabirds and individual vessels and to characterise behavioural changes in birds when associated with fishing vessels. For example, 17 of 25 tracks during the guard stage in 2005-06 included foraging points that were identified as overlapping a trawler. However, eight tracks never overlapped with a fishing vessel while foraging. Other tracking data (GPS, PTT and geolocation) revealed that white-capped albatrosses foraged extensively across the Tasman Sea, around south-eastern Australia, during incubation and chick-rearing, at that birds could potentially overlap with a range of New Zealand fisheries throughout the year, especially since light-based geolocation data revealed that approximately 24% of birds remained close to New Zealand and the eastern Tasman Sea year-round. Other birds migrated farther afield: 40% of birds moved as far as Tasmania and south-eastern Australia, 20% moved westwards to southern and south-western Australia, while the remaining 16% of birds migrated to the south and south-western coasts of southern Africa. These migration patterns are relatively unusual among albatross taxa, other species tend to move to a single, common destination.

As far as we can tell, and despite white-capped albatross encountering a wide range of commercial fishing operations, both within New Zealand and overseas, the relatively high estimate for adult survival would tend to suggest fishing-related mortality is not impacting significantly upon the breeding component of the population. It remains unknown to what extent fishing activity impacts non-breeding, sub-adults or younger birds yet to recruit to the breeding population.

Keywords

White-capped albatross, distribution, population, fishing activity, GPS, satellite telemetry, geolocation

1. **Introduction**

Historically, the white-capped albatross *Thalassarche steadi* was considered part of the larger 'shy albatross' *Diomedea cauta* complex (e.g. Marchant & Higgins 1990), which has subsequently been split into four separate taxa – white-capped albatross, shy albatross *T. cauta*, Chatham albatross *T. eremita* and Salvin's albatross *T. salvini*, following recommendations by Robertson & Nunn (1998). Although the split between white-capped and shy albatrosses, based primarily on genetic studies (Abbott & Double 2003a, 2003b), has been adopted widely (for example, Agreement on the Conservation of Albatrosses and Petrels, ACAP, see http://www.acap.aq/ and BirdLife International, see http://www.birdlife.org/), some authors consider these taxa as sub-species: shy albatross *T. cauta cauta* and white-capped albatross *T. cauta steadi* (for example, Brooke 2004, Onley & Scofield 2007). In this report we follow BirdLife International and refer to white-capped albatross as *Thalassarche steadi*.

White-capped albatross is effectively a New Zealand endemic, breeding primarily at Disappointment Island, South West Cape of main Auckland Island and close to Logan Point on the south side of Adams Island, all within the Auckland Islands archipelago (Taylor 2000: Figure 1), with relatively small numbers breeding at Bollons Island, Antipodes Island group, and at the Forty-Fours, Chatham Islands group (Robertson *et al*. 1997, Tennyson *et al*. 1998, Taylor 2000). Phalan *et al*. (2004) noted that a white-capped albatross was present at a black-browed albatross *Thalassarche melanophrys* colony at Bird Island, South Georgia in the South Atlantic during February 2003, returning the following austral spring. This bird bred with a black-browed albatross each year between 2007-08 and 2009-10, fledging a chick in 2009-10, but was not present at the start of the 2010-11 breeding season (R. Phillips pers. comm.).

An estimate of the Auckland Islands white-capped albatross population in December 2006, based on aerial photography, found 110,649 (95% CI 110,040-111,258) breeding pairs at Disappointment Island and 6,548 (6,400-6,695) breeding pairs at South West Cape (Baker *et al*. 2010). In 2007 these totals were 86,080 (85,493-86,667) and 4,786

(4,648-4,924), in 2008 91,694 (91,088-92,300) and 5,264 (5,119-5,409) and in 2009 70,569 (70,038-71,000) and 4,161 (4,032-4,290) for Disappointment Island and South West Cape, respectively (Baker *et al*. 2010). The number of breeding pairs at Adams Island was relatively small, approximately 100 pairs bred annually between 2007-08 and 2009-10 (Baker *et al*. 2010). These totals represent considerable increases over previous estimates. Robertson (1973) reported 60,000 pairs at Disappointment Island, and by 1993 this total had risen to 72,000 pairs (cited in Gales 1998), although earlier methodologies were not comparable with those employed by Baker *et al*. (2010). It remains to be confirmed whether the declining totals noted by Baker *et al*. (2010) between 2006-07 and 2009-10 represent a genuine downward trend in the white-capped albatross population.

Despite being New Zealand's most numerous breeding albatross species, very little is known of white-capped albatross breeding biology, population characteristics and demography, and at-sea distribution. 'Shy-type' albatrosses (combining white-capped albatross and shy albatross) have been reported as fisheries bycatch off southern Africa (Ryan *et al*. 2002). Abbott *et al*. (2006), using a molecular test based on a nucleotide polymorphism in mtDNA of white-capped and shy albatrosses, noted that all (n = 24) 'shy-type' birds analysed from South African waters were white-capped albatross. Abbott *et al*. (2006) also recorded white-capped albatross from fisheries operating in Western and Eastern Australia and from Tasmania. More recently, Jiménez *et al*. (2009) confirmed that white-capped albatross, predominantly juveniles, associated with the Uruguayan long-line fleet in the south-west Atlantic. Additionally, white-capped albatross has been consistently the most numerous albatross species killed and returned from observed New Zealand fisheries (for example, Conservation Services Programme 2008). This combination of paucity of biological information and relatively high incidence of capture in commercial fisheries resulted in white-capped albatross being classified as 'high priority' for research in the draft National Plan of Action – Seabirds Research Plan.

This report details work undertaken during the 2005-06 through to 2009-10 breeding seasons as part of the Conservation Services Programme project POP2005/02 - A population and distributional study on white-capped albatross (Auckland Islands). The objectives of the project are (1) to collect data describing the at-sea distribution of white-capped albatross, (2) to collect field data to allow estimation of white-capped albatross population size, and population parameters relevant to population viability, and (3) to analyse these data, including estimating population size, population parameters and distribution of white-capped albatross with reference to spatial and temporal fishing effort.

2. Methods

2.1 Study colony selection

The locations of South West Cape (main Auckland Island), Disappointment Island and Adams Island within the Auckland Islands archipelago are shown in Figure 1: these locations hold over 99% of all white-capped albatross breeding pairs. Through a process of discussion with the Department of Conservation (DOC), particularly Southland Conservancy, South West Cape, main Auckland Island was identified as the study site for this project.

The reasons for this selection were as follows: although Disappointment Island holds by far the largest population within the archipelago with approximately 80,000 pairs (Baker *et al*. 2010), or ca. 96% of the total New Zealand population, DOC have classified Disappointment Island as a ‘minimum impact’ island, based on its near-pristine nature and lack of any introduced mammalian predators. Entry to such islands is strongly limited. Adams Island is similarly classified as a ‘minimum impact’ island and in any case supports perhaps only ca. 100 pairs (Baker *et al*. 2010) of white-capped albatross at a site with difficult access. Furthermore, access to and from Disappointment Island is very weather dependent, the only landing being on the west of the archipelago and exposed to the prevailing winds and swells. South West Cape on main Auckland Island supports approximately 4,000 pairs (Baker *et al*. 2010), but unlike both Disappointment and Adams islands, Auckland Island is classified as a ‘refuge’ island. The island is relatively modified, with extant populations of feral pigs *Sus scrofa* (Figure 2), cats *Felis catus* and mice *Mus musculus*. However, and in contrast to Disappointment Island, landing at the South West Cape area, from Western Harbour on the eastern side of the Cape, is relatively straight forward, and very unlikely to be limited by sea and weather conditions as would be the case for Disappointment Island. DOC Southland Conservancy was opposed to the establishment of a potentially long-term study on white-capped albatross at Disappointment Island. Given that the population size of white-capped albatross at South West Cape was relatively large compared to the number of breeding pairs required to undertake demographic work (but see 2.2 **Access to breeding birds** below), coupled with the status of main Auckland Island, South West Cape was selected as the study site.

However, DOC (Southland Conservancy) sanctioned a single, 1-day visit to Disappointment Island during the 2008-09 breeding season so that platform transmitting terminal satellite tags (PTTs) could be deployed on breeding birds (see **2.3.1** below).

2.2 Access to breeding birds

2.2.1 Terrain

At South West Cape, breeding white-capped albatross are located on ledges and fairly level platforms, spread along several kilometres of cliffs and steeply-sloping terrain. The largest concentrations of nests are within an area of sloping ground to the north of South West Cape, bounded to landward by vertical rock faces approximately 40m high. To seaward, the breeding slopes are bounded by further vertical rock faces, which fall away to the sea below. These areas of breeding birds proved unsuitable for the regular access necessary during a long-term population study, despite exhaustive searches along the landward cliff top and the use of ropes to secure exploratory excursions down the more likely slopes and faces towards the birds below.

Access to and from these areas of relatively large numbers of breeding birds would be theoretically possible, but would involve rock climbing of a highly technical nature. We considered such an approach to be excessively dangerous and high-risk given the perpetually greasy and wet condition of the rock, the relatively shallow soil structure above the cliff and on ledges, which rendered the soil prone to ‘sliding off’ the underlying rock, and the generally inclement weather characterised by high winds and mist. As an area for a study population, requiring regular access, these sites would be unsuitable.

Elsewhere within the South West Cape area, birds were either similarly inaccessible on ledges or slopes down precipitous cliffs, in relatively small numbers (a few tens of pairs) in a very small number of areas that were accessible to us, but inaccessible to pigs (see below), or in areas with relatively easy access, but which were also, therefore, accessible to pigs.

2.2.2 Pigs

Feral pigs were seen on a daily basis on all field trips in all but the most inaccessible parts of the white-capped albatross colony at South West Cape. Vertical slopes and bluffs of at least 1m high appeared to act as a barrier to pigs, but their ability to navigate steep and treacherous terrain was surprising. Birds which constructed nests in areas accessible to pigs were usually unsuccessful and in many cases had nest pedestals completely destroyed (Figure 3). The presence of pigs throughout large areas of the colony was a further factor limiting the selection of a study site within the South West Cape area.

2.2.3 The study site

Following a thorough search of the entire South West Cape area during the first field visit during the 2005-06 breeding season, an area of relatively steeply-sloping ground was identified (Figure 4) as a suitable study site. This area was bounded on its upper side by a series of vertical bluffs and crags that were very likely to be a barrier to feral pigs. On the lower edges of the site the ground fell away to the sea in a single, vertical drop. That feral pigs were prevented from accessing the area was further confirmed by the presence of the carrot *Anisotome latifolia,* which was entirely absent from areas accessible to pigs. Access to and from the study site was facilitated through the use of climbing ropes in the first year of the study, and via a semi-permanent rope ladder in subsequent years. While we are confident that feral pigs were not able to gain access to the area, we observed feral cats and mice among the nesting white-capped albatross on a few occasions. However, and unlike the effects of pigs, it is extremely unlikely that cats and mice had any significant effect on breeding birds.

The study site was relatively modest in area, and held between 30-50 breeding pairs in each of the years of study.

As noted above, we made a single visit to Disappointment Island during the 2008-09 breeding season. We landed at Castaways Bay on the eastern side of the island and were able to deploy PTTs on nesting birds on the north-western side of the bay, above the boatshed site.

2.3 Fieldwork programme, data collection and data processing

2.3.1 Field visits

Table 1 summarises fieldwork undertaken primarily at the South West Cape study colony, but also includes the single visit to Disappointment Island, in relation to breeding season stages.

2.3.2 Field methods and data collection

2.3.2.1 Bird considerations

In addition to restricted or impracticable access to relatively large, pig-free areas of the colony at South West Cape, and the deleterious effects of pigs (see above), the responses of the birds when approached or handled also posed some problems. Capture of birds was necessary for the application of uniquely-numbered metal leg bands and for deployment and retrieval of tracking devices. Some birds responded negatively to capture (by hand), responses ranging from birds taking several minutes to 'settle' back on the nest following release (all birds were placed on the edge of a nest pedestal following handling as early 'trials' revealed that birds released close to the nest were unlikely to climb back onto the pedestal), leaving the nest pedestal completely, leaving the nest and attempting to fly away or actually flying away from the nest site for periods ranging from a few minutes to approaching two hours. In an extreme case, one bird flew away from its nest and chick even though field workers had only approached to within approximately 15 m of the nest site. When birds flew away from the colony after handling, exposed eggs or small chicks could easily be preyed upon by patrolling brown skuas *Catharacta lonnbergi*. In all cases where eggs or chicks were temporarily abandoned by adult birds, field workers remained near the nest to ensure skuas were unable to prey upon nest contents until birds returned. All birds that responded in this way eventually returned to the nest and continued incubating or guarding the chick.

In some cases, handled birds had to be 'corralled' by two or three field workers around the nest site in order to encourage the bird to stay. Only when the bird showed signs of settling back onto the nest could the field workers corralling the bird retire with confidence that the bird would not fly away.

In short, white-capped albatross appears to be a species that can respond badly to handling. However, over the years of the study it was possible to identify birds that were particularly vulnerable to disturbance and these individuals were generally avoided as subjects to carry tracking devices and were only handled once in order to apply a metal leg band.

2.3.2.2 Life history parameters

During fieldwork in 2005-06 through to 2008-09, all breeding birds encountered at the study site were equipped with a uniquely-numbered metal leg band (Table 1), and nest pedestals were marked with numbered tags. In breeding seasons 2006-07 through to the end of the study, band numbers of re-sighted banded birds were recorded, as was information regarding whether birds were actively breeding or not: presence or absence of an egg or chick. From the second field season onwards it became clear that not all birds attempted to breed in every year. Furthermore, some marked birds from the study area would return to their nest sites, particularly during the early stages of the breeding season, even if they were not actively breeding in that year. Sightings of banded birds, and breeding success estimates, were used to derive estimates of adult survival, breeding frequency and breeding probability estimates. As noted in Thompson *et al*. (2009) these estimates were derived using NIWA's SeaBird model (Francis 2010).

2.3.2.3 Distributional data

Three different devices were deployed in order to gather at-sea distributional data for white-capped albatross (Table 1). Two of these were data-logging devices and required recapture of the bird, device retrieval and data downloading: global positioning system (GPS) loggers (Earth & Ocean Technologies, Kiel, Germany; 'GPSlog' and 'MiniGPSlog' tags, maximum of 1.5% of white-capped albatross body mass) and light-based geolocators (British Antarctic Survey, Cambridge, England; 'Mk5' and 'Mk7' loggers, maximum of 0.1% of white-capped albatross body mass). The third type of device, platform transmitting terminals (PTTs), transmits positional data to orbiting satellites of the ARGOS array and do not require retrieval in order to acquire location data (Sirtrack Ltd., Havelock North, New Zealand; 'KiwiSat 202' PTTs, maximum of 1% of white-capped albatross body mass).

Geolocator tags were attached to either a custom-designed leg band or a standard plastic leg band using plastic cable ties fitted with stainless steel lugs to prolong attachment (Figure 5). In some cases, quick-setting ‘super glue’ was applied to the lugs. For both GPS and PTT tags, devices were attached to dorsal feathers between the wings using water-resistant Tesa© tape. In all cases, birds were captured by hand to facilitate device attachment. Wherever possible birds were recaptured in order to retrieve devices, and although this wasn’t necessary for data acquisition in the case of PTTs (see above), where birds returned to the colony carrying a PTT capture was attempted. In all cases, deployment and retrieval of tracking gear took less than five minutes.

GPS tags were configured to acquire a positional fix every three to six minutes, locations accurate to within a few metres (90% of locations were within 19 m of the ‘true’ locations: Earth & Ocean Technologies, unpublished data). PTTs were configured with a transmission rate of either 40 or 90 seconds with no duty cycle. Although the transmission rate was relatively frequent, locations were only acquired if a minimum of three ARGOS satellites were detected by the tag. Typically, between 20 and 40 usable locations were acquired each day, with accuracy ranging from a few hundreds of metres to the order of kilometres. An iterative speed-based filtering process was used to remove inaccurate and unfeasible locations (McConnell *et al*. 1992, BirdLife International 2004). In the case of light-based geolocator tags, daily positions were calculated from ambient light level readings with reference to time and date – latitude from day (night) length and longitude from the time of local midday (midnight) relative to Greenwich Mean Time. Positional accuracy is much less compared to PTT or GPS devices, perhaps to within 150-200 km (Phillips *et al*. 2004), but devices can log data over relatively long periods (several years) making geolocator tags ideal for determining relatively large-scale movements typical of migrations.

2.3.3 Commercial fishing data and relationships with bird distributional data

For all white-capped albatross distributional data, corresponding information about commercial fishing activity was acquired through the Ministry of Fisheries (MFish). In all cases, fishing data were provided that corresponded to the same spatial and temporal extent as the albatross data. Catch-effort data, effectively the start locations of fishing events, were supplemented by Vessel Monitoring System (VMS) data in the case of bird GPS data. The high-resolution (both spatial and temporal) characteristics of bird GPS data provided an opportunity to quantify the nature and extent of bird-boat interactions at a fine scale (see below). In the case of PTT and geolocation data, both of which are of considerable lower spatial and temporal resolution compared to GPS data, bird distributions were compared to fishing effort data through kernel density plots or through visual comparisons of plots of filtered data points. Because white-capped albatross foraged in Australian waters (see **3.2 Tracking studies** below**)** we attempted to acquire information on the distribution and activities of Australian commercial fishing vessels. These attempts proved unsuccessful, despite exploring several avenues, and we were unable to acquire any fishing data with which to compare to white-capped albatross distributions outside New Zealand waters.

GPS data acquired during the guard stage of the breeding season in 2005-06 and 2009-10 provided an opportunity to compare bird movements, distributions and at-sea behaviour with fishing vessel distributions and activities at a very fine scale: effectively examining the relationships between birds and boats at an individual (both bird and boat) scale. However, due to device issues during the 2009-10 guard stage deployment, only the GPS data from 2005-06 breeding season have been examined in this way. This component of the project has been published as Torres *et al.* (2011), and the main points have been reproduced here as part of this report.

2.3.3.1 Quantifying association between white-capped albatrosses and fishing vessels

We focused on the relationship between the commercial squid trawl fishery and the distribution of white-capped albatrosses because this was the only fishing activity that occurred during the same temporal period and spatial extent as the bird tracks. Fine-scale fishing effort data were deduced using two datasets provided by the New Zealand Ministry of Fisheries. Every New Zealand fishing vessel exceeding 28 m in overall length and all foreign fishing vessels in New Zealand's Exclusive Economic Zone are required to carry a GPS transponder. This Vessel Monitoring System (VMS) accurately records a vessel's location in time and space, but data points are typically only acquired every 1-2 hours and, besides speed, no vessel activity data (for example, fishing, setting or hauling a net) are recorded. In addition to this VMS dataset, we used a Catch Effort database (Ministry of Fisheries 2006) that provided locations and times for every trawl event (sets and hauls). Although this Catch Effort dataset provides vessel activity data, the accuracy of event locations, in time and space, is low relative to albatross GPS tracks and VMS data. Locations of sets and hauls were recorded to the nearest minute and time stamps were frequently rounded to 5 minute increments, producing potential spatial error of up to 2 km and unknown temporal error. We integrated the VMS and Catch Effort datasets to identify overlap and interaction points between all recorded albatross tracks and fishing effort.

First, we used the VMS dataset to identify points along the albatross tracks that overlapped spatially and temporally with a fishing vessel. VMS points are highly accurate, yet we do not know the vessel's exact location in between consecutive points. Therefore, we generated circular spatial buffers of variable radii sizes around interpolated points placed at 3-minute intervals along a straight-line path between consecutive VMS points. (A full description of methods used to identify overlap between albatross GPS points and fishing vessels can be found in Appendix 1). Three-minute intervals were used because this was the same sampling rate as the albatross GPS tags. The radius size of each circular spatial buffer was calculated based on the fact that the location of the vessel at the two end (VMS) points is certain, but the position of the vessel becomes more uncertain with increasing distance from these end (VMS) points. Therefore, the size of the circular buffers around each 3-minute point is based on its distance from the closest end point, with the mid-point having the largest buffer because this point has the greatest uncertainty of the vessel's location (Figure 6).

Radius buffer sizes were calculated as follows. For every pair of consecutive VMS points, we calculated the 'excess distance' (eD) between those points, defined as the extra distance, in addition to the actual distance between points, the vessel could have travelled if it maintained a constant speed and travelled in a straight line between the two VMS points. The eD was calculated as the difference between the potential distance the vessel could have travelled (average vessel speed * time between start and end points) and the actual distance between the start and end locations. Theoretically, the farthest the vessel could have travelled off the straight-line track from the initial VMS point and still make it to the end VMS point in the same amount of time is 0.5(eD). This maximum distance of the tangent line from the initial VMS point occurs at the mid-point of the track (c = eD / 2). Based on the Pythagorean theorem ($a^2 = b^2 + c^2$), the value of c, and the distance to the mid-point from the end points (b), we calculated the radius size (a) for the spatial buffer at the mid-point. The radii sizes (r^i) for all other 3-minute points along the straight-line vessel track were calculated as an incremental proportion of the value of a, increasing in size with increasing distance from the closet VMS point. Finally, albatross track GPS points were overlaid on the spatial buffers to identify the overlap state (overlapping or non-overlapping) of each point. Those points that fell within the radius buffers and within a ±3 minute temporal window of the VMS point or interpolated 3-minute intervals along the vessel tracks were identified as overlapping. Code was written in Matlab® to iteratively perform these spatial and temporal comparisons between every albatross and fishing vessel track.

Next, we cross-referenced all albatross GPS points identified as overlap with the Catch Effort dataset to identify 'interaction' points with trawlers. We focused on haul and set locations to identify potential interaction points because this was the dataset available to us and where relatively high mortality rates of white-capped albatrosses are likely to occur (Bartle 1991). For every overlap point, we determined if the associated vessel performed either a set between the recorded bird time and minus 30 minutes, or a haul between the recorded bird time and plus 30 minutes. On average, hauls and sets take about 20 minutes to complete (Baird 2008), and set times are not recorded until the net reaches its fishing depth and haul times are recorded when the net leaves its effort depth. However, to an albatross, a set begins when the net first hits the water and a haul does not end until the net leaves the water (Bartle 1991). Therefore, the time window of interaction for the set period was determined to be the recorded set time minus 30 minutes, and for the haul period was determined to be the recorded haul time plus 30 minutes. Finally, only points designated as foraging (residence value in the top quartile of the track) were considered interaction points, otherwise the bird was considered to be travelling through the area and not actually interacting with the vessel.

3. Results

3.1 Breeding and life history parameters

White-capped albatross commenced egg-laying in mid-November, with hatching underway by mid-January, extending into early February. Chicks were guarded for approximately three weeks, centred on February, and fledging of chicks took place in June (based on colony departure by adults equipped with geolocation tags).

Over the course of the project, a total of 70 nests were identified and numbered as part of the ‘slope’ study area. All but 12 breeding birds associated with these nests were banded with a uniquely-numbered metal leg band. Not every nest in the study area was used annually: at the guard stage there were 26 active nests in 2005-06, 18 in 2006-07, 27 in 2007-08, 34 in 2008-09 and 21in 2009-10. In the very brief visit during incubation in 2010-11 there were active 22 nests. Although these numbers do not include active breeding attempts that failed prior to the guard stage, they are all substantially fewer than the total number of marked nests used during at least one year over the course of the project.

Additionally, birds that bred in one year tended not to breed the following year. Of those pairs that had a chick at the guard stage in 2005-06, 38% also had a chick at the guard stage in 2006-07. Similarly, 37% of pairs with chicks in 2006-07 returned to breed and had chicks at the guard stage in 2007-08. Just over half of pairs (52%) with chicks in 2007-08 also had chicks at the guard stage in 2008-09, and of those with chicks in 2008-09, 41% also had chicks at the guard stage in 2009-10. Although the colony was not visited at the guard stage in 2010-11, 44% of pairs with chicks in 2009-10 returned to breed and had an egg during the incubation stage in 2010-11. These results are supportive of SeaBird modelling outputs: Francis (2010) reported the probability that a bird that bred in one year would also breed in the next year to be 0.63, whereas the probability that a bird that didn't breed in one year but which would breed in the next year was 0.78.

Francis (2010) determined the annual probability of adult survival to be 0.96, based on all available re-sighting information from the 2006-07 to 2009-10 breeding seasons.

3.2 Tracking studies

3.2.1 GPS

GPS tags were deployed in all years except 2006-07.

In 2005-06 we deployed 20 GPS tags during the guard stage (Table 1). Tags were successfully retrieved from 19 white-capped albatrosses and recorded 25 foraging trips, six birds having completed two trips while tagged. Figure 7 illustrates all tracks, showing that the birds travelled to diverse destinations. However, a concentration of tracks is evident in one area over the Auckland Islands shelf, at the 250 m isobath to the east of the Auckland Islands archipelago. In fact, 13 out of the 25 foraging trips did not extend beyond this area. Of the 12 remaining tracks that dispersed beyond this area, seven tracks also occurred over the Auckland Islands shelf during a portion of the foraging trip. Only five of 25 tracks did not travel through the Auckland Islands shelf at any time. The radius buffering method of VMS tracks produced buffers with radii sizes ranging from <100 m to 28 km, yet 91% of all buffers had a radius less than 7 km. Spatial buffers with radii larger than 7 km are due to long time gaps (> 2 hrs) between VMS points. Additionally, 95% of all buffers that overlapped with an albatross GPS point in space and time had radii less than 7.5 km. These results indicate that a relatively small scale of analysis was maintained to evaluate overlap between individual white-capped albatrosses and individual trawl vessels (Torres *et al*. 2011).

Based on the radius buffering method of VMS data, 17 of 25 tracks (68%) included foraging points that were identified as overlapping a trawler. Unsurprisingly, a strong majority (99%) of these overlap points occurred in the Auckland Islands shelf region where most of the fishing activity occurred. Eight tracks never overlapped with a fishing vessel while foraging. Additionally, the six tagged birds that completed two foraging trips while tagged were not consistent in their destination or in their rate of overlap with fishing vessels. This result indicates that individuals vary their foraging patterns between trips. On average, tracks overlapped with ten (SE = 1.3, maximum 17) different trawlers per trip. Eleven of 25 tracks included foraging points identified as interaction events, and of the 19 tracked birds, 10 interacted with a trawler at some point during a foraging trip (Torres *et al*. 2011).

In 2007-08 a total of 15 GPS tags loggers were successfully deployed on incubating birds. In the absence of any information on incubation phase foraging trip length for white-capped albatross, we based our tag sampling protocols and deployment strategy on data available for the closely related shy albatross - incubation phase foraging trips in shy albatross last, on average, 2.8 days (Hedd *et al*. 2001), we found that for nine birds carrying a GPS logger, the average time spent on the nest following deployment was approximately eight days (range 4-10 days). Furthermore, this value is obviously an underestimate of ‘true’ incubation shift length as each of these birds would have been incubating for an unrecorded number of days prior to GPS deployment. Similarly, for five birds that were relieved by their partners and left the colony, the minimum trip length averaged approximately 7.5 days – these birds were not seen at the colony again before our departure, so the ‘true’ trip length would have been longer. Such relatively long incubation phase shift lengths were not anticipated for white-capped albatross based on information available for shy albatross (see above), and using shy albatross as a model clearly resulted in underestimation of incubation phase foraging trip lengths in white-capped albatross and limited our ability to gather tracking data using GPS loggers. We were able to retrieve incubation phase foraging trip data from four GPS loggers: these trip data are summarised in Figure 8. Only one data set produced a complete track, that from a bird away from the colony for only two days which travelled to the southwest of the colony. The remaining three tracks were incomplete with all birds still many hundreds of kilometres from South West Cape – two birds were to the east of Australia, the third just west of the Chatham Islands (Figure 8).

A total of 16 GPS tags were deployed on incubating adults in 2008-09. Of these, one was lost due to the bird deserting its nest (the only time this happened during the course of the study), and a further five loggers were removed before incubating birds left the colony, having remained on the nest for a minimum of 11 days. One additional logger was missing from the bird at recapture following a foraging trip and two devices malfunctioned and yielded no usable location data. The remaining seven loggers produced viable data that indicated birds travelled relatively large distances away from the Auckland Islands during the incubation stage of the breeding season (Figure 9), as was previously noted for the 2007-08 breeding season, including areas to the south-east of Australia, to the east of Stewart Island and along the east coast of South Island.

In 2009-10, a total of 18 GPS tracks were obtained during the guard stage from 20 tags deployed – two birds failed to return to the colony before we departed. Tracks are summarised in Figure 10. Several tags failed to collect data over portions of the track for reasons we could not determine (these gaps in the data are clearly visible in Figure 10), precluding a comparable, detailed analysis of bird-boat interactions as undertaken for data from 2005-06 (see above). However, it was possible to convert these bird GPS data into a kernel density plot (Figure 11), which highlights areas of high-use by albatrosses immediately to the southeast of the Auckland Islands and directly to the north of the islands (Figure 11). In 2009-10, there was no evidence that birds made much use of the area over the Auckland Islands shelf to the east of the islands as was the case in 2005-06 at the same phase of the breeding cycle. Furthermore, compared to a kernel density plot of fishing events over the same temporal window that birds were tracked in 2009-10 (Figure 12), the birds appear not to associate to the same extent with fishing vessels in 2009-10 as they did in 2005-06. Fishing effort was concentrated in two areas, one to the east of the Snares Islands, along the Snares shelf, the second off the south Otago coast (Figure 12) – neither area featuring in a similar plot of bird distributions (Figure 11).

3.2.2 PTT

PTTs were deployed during the guard stage in 2005-06, the chick-rearing stage in 2006-07 (both at South West Cape) and from the incubation stage through to the chick-rearing stage in 2008-09 (at Disappointment Island: Table 1).

In 2005-06, PTTs were deployed at the same time as GPS tags (see **3.2.1** above), and perhaps unsurprisingly produced tracks (Figure 13) with a very similar distribution to those acquired from the GPS tags (Figure 7). One bird, which deserted its nest several days after device deployment, moved across the Tasman Sea to Tasmania, but the remaining tracks show a cluster of fixes to the east of the Auckland Islands, in an area used extensively by birds fitted with GPS tags. Because the GPS data were of much higher spatial and temporal resolution than the PTT data collected at the same time, the GPS data were used, in preference to the PTT data, for a comparison with fishing vessel distributions.

In 2006-07, the study colony was visited during the chick-rearing stage of the breeding season (Table 1). Because chicks are left unattended by both parents at this time except for sporadic feeding visits, which can be a short as five minutes in duration, it is very difficult to retrieve deployed tracking gear. A total of seven PTTs were deployed which transmitted data throughout March and April, but which began to fail or fall off birds into May. Kernel density plots of filtered PTT locations for March and April, together with corresponding plots of fishing events are shown in Figure 14. The distribution of white-capped albatross at this time, centred primarily to the north of the Auckland Islands in March and to the east of the Auckland Islands in April overlaps with similar areas of relatively fishing activity (Figure 14).

In 2008-09, 15 PTTs were successfully deployed on incubating birds at Disappointment Island, there were no nest desertions. Overall, these tags provided location and tracking information for between 0 and 23 foraging trips per bird that extended into April 2009. We cannot rule out the possibility that some devices were removed by the birds, but it also appears likely that some devices malfunctioned relatively soon after deployment, with some failing well before the expected 90-day operating lifespan. Kernel density plots derived from bird locations, and corresponding plots of fishing events have been produced for December 2008 through to April 2009 inclusive. During December and January (incubation stage) birds visited areas to the southeast of Australia and between the Auckland Islands northwards to the south and east of South Island (Figure 15). The at-sea distribution of Disappointment Island birds contracted during February (guard stage) and March (early post-guard chick rearing) to areas immediately to the north of the Auckland Islands extending to the west of Stewart Island (Figure 16). During April (chick-rearing), the few PTTs/birds that continued to transmit location data revealed that areas to the south-east of Australia were again visited, but that the zone between the Auckland Islands and southern South Island was also popular (Figure 17).The distribution of birds from Disappointment Island during December was not dissimilar to that of birds tracked using GPS tags at South West Cape (Figure 18). Both groups of birds traversed the Tasman Sea to areas south-east of Australia, and areas to the south and east of South island were also favoured (Figure 18).

The kernel plots of PTT data from birds at Disappointment Island have been compared to similar kernel plots of fishing event start locations over corresponding temporal windows (Figures 15-17). Generally, overlap with fishing effort was more notable during March and April in particular, with a key area immediately to the north of the Auckland Islands (Figures 16 and 17). During February there was some overlap to the north of the archipelago (Figure 16), but overlap was less distinct during December and January (Figure 15).

3.2.3 Geolocation

3.2.3.1 Bird location data

A total of 25 geolocation data sets, from 25 different birds, were acquired from 46 geolocation tags deployed over the first three years of the project. Some tags were lost from birds while others failed to function properly and contained no data when retrieved. Of the 25 birds from which geolocation data were acquired, the majority (21 out of 25, 84%) remained in Australasian waters year-round. Of these 21 birds, six (24% of all birds) remained close to New Zealand and the eastern Tasman Sea and 15 had larger distributions which extended as far westwards as southern and south-western Australia (five birds or 20% of the sample), or as far as Tasmania and south-eastern Australia (ten birds or 40% of the sample). The remaining four birds (16%) migrated to the south and south-western coasts of southern Africa, their distributions extending northwards within the Benguela system off Namibia. In all cases, birds were consistent in their non-breeding destination – individuals that migrated to southern Africa did not, as far as we could tell, also spend non-breeding periods within Australasia, and those individuals that migrated only as far as Australia or which remained close to New Zealand did not migrate to southern Africa.

These geolocation data have been summarised as plots based on the stage of breeding cycle, and for November-January (incubation), February (guard) and March-June (chick-rearing) further segregated into plots for birds actively breeding and for birds known to have failed in a breeding attempt or which were not breeding during a particular year. All geolocation data were combined for a plot spanning July-October (non-breeding) as all birds would not be breeding at this time. Figure 19 shows locations during the incubation phase for breeding and non-breeding birds: apart from one breeding bird returning to New Zealand, both distributions are remarkably similar, with birds moving across the

Tasman Sea to forage around Tasmania and along the south-eastern coast of mainland Australia, as well as locations mainly to the west of South Island and extending southwards into New Zealand's sub-Antarctic region. These data indicate that even for those birds that spend the non-breeding period off southern Africa, all birds return to New Zealand waters, whether breeding or not, for the start of the breeding season.

Figure 20 shows data from the guard phase. Breeding birds exhibit a more restricted distribution that extends north-westwards into the Tasman Sea but which does not extend as far as Australia. Areas to the east of New Zealand tend not to be utilised by breeding birds. In contrast, non-breeding birds have a more extensive distribution at this time, reflecting in part some failed breeding birds that have begun their westward migration but also reflecting a lack of constraint in having to return to South West Cape and feed a chick.

Figure 21 illustrates locations from the chick-rearing period, which for breeding birds show an expanded distribution, compared to the guard stage (Figure 20), similar to that during the incubation phase (Figure 19). Breeding birds travel across the Tasman Sea to feed off south-eastern Australia, but rarely venture north of South Island to the east, and appear not to utilise the Chatham Rise to any extent. Non-breeding birds at this time have already moved to migration destinations off Africa and southern Australia, but have a similar distribution to breeding birds around New Zealand.

Figure 22 shows locations during the non-breeding period (July-October) for all birds combined – with 'centres' of distribution around New Zealand, the eastern coastal areas of Australia, the central-southern zone of Australia and off Africa. Those birds that migrated to Africa travelled westwards at relatively northern latitudes through the Indian Ocean, and returned eastwards to New Zealand at more southerly latitudes, presumably to take advantage of prevailing wind systems.

3.2.3.2 Comparison between bird and boat distributions

To compare white-capped albatross distributions derived from geolocation tags (Figures 19-22) with fishing activity, plots of fishing events over the entire period of geolocation tag deployment and covering the entire New Zealand EEZ have been produced for four fisheries with which white-capped albatross are known to interact (Conservation Services Programme 2008). These fishing event plots (Figures 23-30) have been aligned temporally with white-capped albatross breeding cycle phase, and although the data are at a relatively coarse scale, patterns in the overlap between birds and boats can be detected.

Figures 23 and 24 illustrate fishing events targeting squid *Nototodarus* spp. Clearly, white-capped albatross distributions (Figures 19-22) overlap with the main areas of interest of the squid fishery to the south and east of South Island at all phases of the breeding cycle. In contrast, Figures 25 and 26 illustrate the distribution of fishing effort targeting hoki *Macruronus novaezelandiae*, which extends along the Chatham Rise and coastally to the northeast of North Island at all phases of the birds' breeding cycle: these areas are little-used by white-capped albatross. During the chick-rearing and non-breeding phases of the breeding season, hoki effort is also concentrated along the west coast of South Island, an area of overlap with bird distributions. Southern bluefin tuna *Thunnus maccoyii* fishing effort is illustrated in Figures 27 and 28. There is virtually no fishing in New Zealand for this target during the incubation and guard stages (November to February), but effort increases markedly during the chick-rearing phase off the southeast of South Island, overlapping with birds at this time. During the non-breeding period, most southern bluefin tuna effort has moved off the east coast of North Island and out of range of most birds. Fishing effort directed at scampi *Metanephrops challengeri* (Figures 29 and 30) is uniform in distribution throughout there year. Overlap with white-capped albatross is most likely for those vessels operating close to the Auckland Islands, other areas of interest to the fishery being less-favoured by the birds.

4. Discussion and Conclusions

4.1 General

It is perhaps worth noting that prior to this project, virtually nothing was known about the breeding biology, life history characteristics and at-sea distributions of white-capped albatross, except for records of capture by commercial fishing vessels. During this project's time frame, Baker *et al*. (2010) also provided the most up to date and reliable population estimates, improving substantially upon earlier work (summarised in Gales 1998), although it remains to be seen whether the apparent decline in numbers of breeding birds noted by Baker *et al*. (2010) between 2006 and 2009 represents a genuine, negative population trajectory.

Whatever the ultimate conclusion of the white-capped albatross population work, it is clear that this is the most numerous breeding species in the New Zealand region, and likely to be the third most abundant species globally, after black-browed albatross *Thalassarche melanophrys* and Laysan albatross *Phoebastria immutabilis* (Gales 1998). Although numerous, establishing a study population at the Auckland Islands was not straight forward. Logistically challenging and constrained by limited access to some island breeding locations, the eventual choice of South West Cape was in some respects less than ideal. The largest concentrations of breeding birds at South West Cape were effectively inaccessible and feral pigs have a negative impact on all white-capped albatross nests which they encounter (Flux 2002). Nevertheless, it has been possible to establish a relatively small study population, free of pigs, which has yielded new and valuable information on both population parameters and at-sea distributions and foraging patterns.

4.2 Population studies

Prior to this project, white-capped albatross was assumed to be an annually-breeding species, in line with other members of the 'shy' group of albatrosses. Observational data of breeding occurrence and frequency, coupled with modelling outputs from the SeaBird model (Francis 2010) do not support this assumption. Although it proved impossible to follow all white-capped albatross breeding attempts in the study area to completion (either chick fledging or definite breeding failure in), and therefore relate breeding frequency to breeding success or failure in the previous attempt, only 37-52% of pairs that had a chick at the guard stage in one year returned to breed the following year. These values are likely, for the reasons noted above, to be slightly over-estimates. So while white-capped albatross appears not be extremely biennial in its breeding strategy, clearly it is not an annual breeder either. This result has implications for the population estimates undertaken by Baker *et al*. (2010), since year-to year variation in breeding numbers will be much larger in a non-annual breeding species making interpretation of any population trajectory more difficult.

Using the mark-recapture data acquired as part of this project, Francis (2010) determined adult survival to be 0.96, which is as high or higher than some recent estimates of survival in other albatross species (Converse *et al*. 2009, Rolland *et al*. 2010, Barbraud & Weimerskirch 2011). Taken at face value, this relatively high estimate of adult survival is at odds with the apparent decline in breeding population between 2006 and 2009 reported by Baker *et al*. (2010). An alternative explanation could be that an increasing number of birds are electing not to breed over recent years, for reasons we do not understand, rather than for a relatively large number of birds to have been killed over this period (estimated by Francis (2010) to be over 20,000 adults annually).

4.3 Distribution studies

The ongoing miniaturisation of GPS tracking technology, and its application to seabird studies, affords an unprecedented level of resolution to be achieved, in both time and space. When coupled with similarly high-resolution position and activity data from commercial fishing vessels, for example through a Vessel Monitoring System, it is possible to examine the real interaction between birds and boats at an individual level (Granadeiro *et al*. 2011, Torres *et al*. 2011), rather than by integrating data to more coarse levels (Votier *et al*. 2010) or by using inherently coarse data, for example PTT or geolocation data in the case of birds (BirdLife International 2004, Phillips *et al*. 2006, Walker & Elliott 2006). Our approach outlined here and published separately (Torres *et al*. 2011) is a first step in developing a set of protocols to combine high resolution bird and boat data in order to quantify fine-scale overlap between individual seabirds and individual vessels and to characterise behavioural changes in birds when associated with fishing vessels. This approach results in a more refined understanding of how and when birds interact with fishing vessels, and for white-capped albatross showed, for example, that not all birds foraged and overlapped with commercial fishing vessels even when there were relatively large numbers of boats relatively close to the breeding colony.

The PTT-derived locations acquired from breeding birds at Disappointment Island were the only data obtained from this, the largest white-capped albatross breeding colony. The field team were allowed a single visit to the island and retrieving tracking gear was not possible. Although some PTT devices malfunctioned, sufficient information was gathered to be able to conclude that overall distribution patterns of birds at Disappointment Island were similar to those from South West Cape. This finding is perhaps not surprising given the relatively small distance between the two sites (Figure 1), but nevertheless confirms that birds from the smaller, pig-influenced South West Cape colony can be considered representative of the population as a whole. The utility of PTT tags as a tool to track seabirds is waning – they are relatively expensive, data acquisition via the Argos satellite array incurs a further cost and data resolution, both in time and space, is relatively poor compared to GPS technology. However, for situations where device retrieval is impossible or unlikely, PTT tags are often the only tracking option.

The geolocation data described here revealed several important features of the year-round distribution of breeding and non-breeding white-capped albatross. Firstly, white-capped is relatively unusual among albatrosses in that it exhibits a dichotomous migration strategy: a majority of birds (approximately 80%) remaining in Australasian waters year-round and a smaller, but not insignificant component (approximately 20%) of the population migrating westwards across the Indian Ocean to spend the non-breeding period off South Africa and Namibia, in the Benguela upwelling system. Even among those birds that remained within Australasia, approximately 30% remained within New Zealand waters year-round. There are relatively few published examples of similarly distinct migration strategies, resulting in birds occupying separate regions, among albatross. BirdLife International (2004) noted that most black-browed albatross at Diego Ramirez off the southern tip of South America migrated northwards along the western coast of Chile, but that some birds (proportion unspecified) migrated to northern New Zealand. Phillips *et al*. (2005) tracked the same species from South Georgia in the south Atlantic Ocean and found that most birds (94% of 35 individuals) wintered in the Benguela system off southwest Africa, but that one bird migrated as far as southern Australia while the remaining bird wintered primarily on the Patagonian shelf in the southwest Atlantic Ocean. Phillips *et al*. (2005) also noted that as far they could tell, individuals were consistent in their choice of wintering destination, a pattern found in the present study of white-capped albatross.

The divergent migration strategies of white-capped albatross (southern Africa versus Australasia) have important implications for the extent to which birds are likely to encounter and overlap with commercial fishing vessels. Petersen *et al*. (2008) found that non-breeding white-capped albatross in the Benguela system spent about 85% of their time on the southern African trawl grounds, and estimates of white-capped albatross mortality in southern African fisheries extend to thousands of birds annually (Baker *et al*. 2007, Watkins *et al*. 2008). If accurate, these mortality estimates would have a severe impact on the small proportion of the white-capped albatross population that migrates to Africa.

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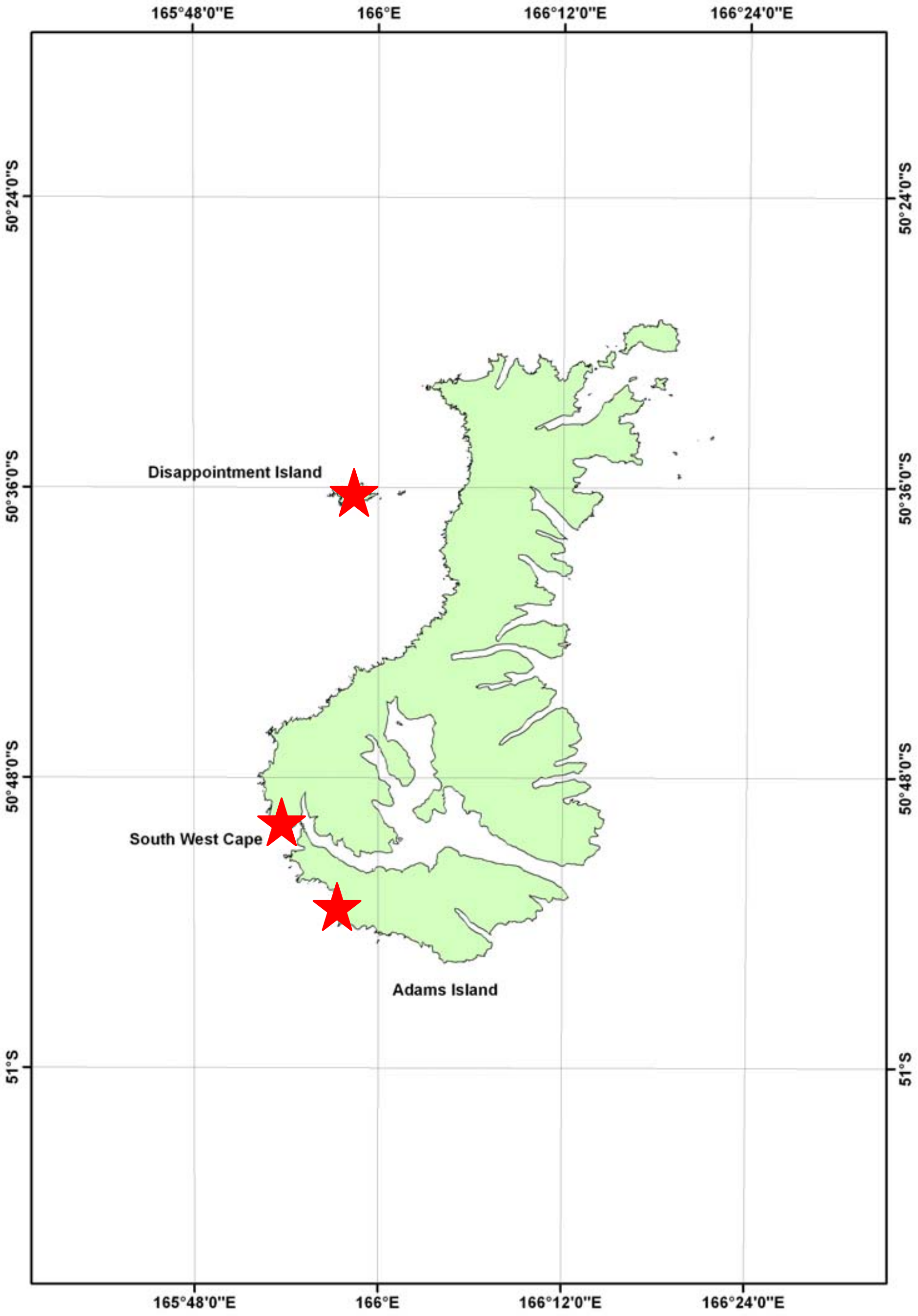


Figure 1. Map showing the locations of the three white-capped albatross breeding sites within the Auckland Islands archipelago. Birds breed at locations marked with red stars: over much of Disappointment Island, at South West Cape (main Auckland Island) and on the south coast of Adams Island.

Figure 2. Feral pig *Sus scrofa* above the study area at South West Cape.

Figure 3. The site of a white-capped albatross nest pedestal destroyed by a feral pig. An intact nest in the background was left untouched by the pig.

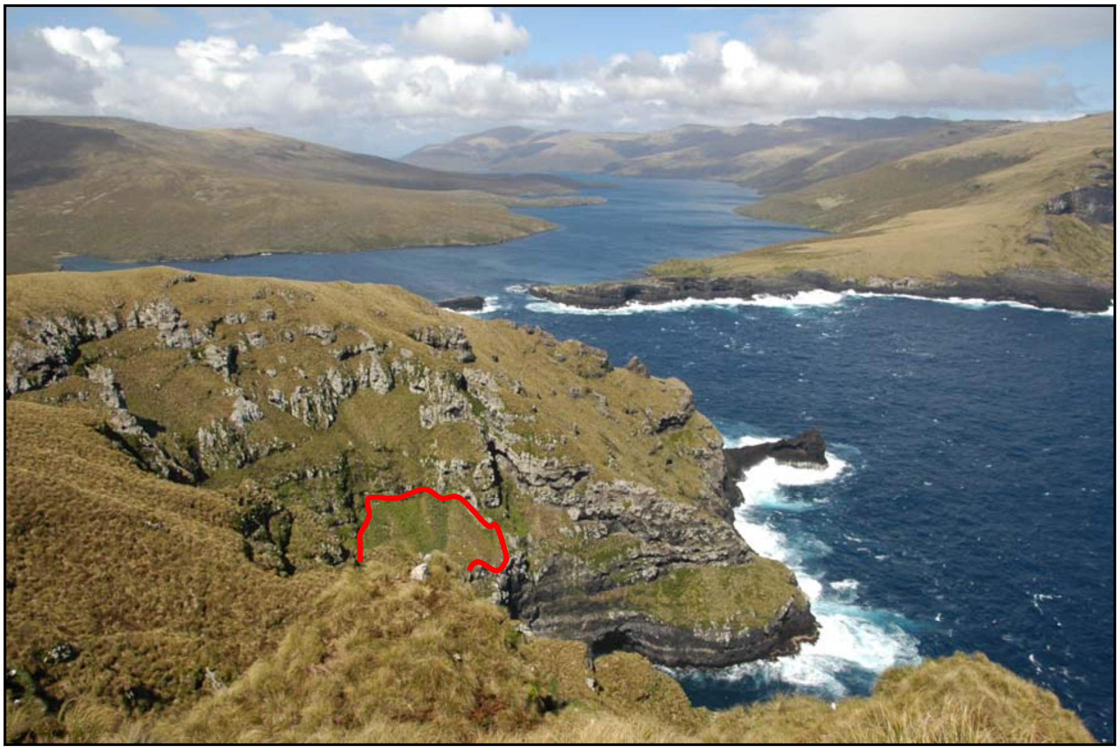


Figure 4. White-capped albatross study area, within red line, on a southwest-facing slope within the South West Cape area. Note rocky bluffs immediately above area, which prevent access for feral pigs. Adams Island is to the right of the image, main Auckland Island to the left, with Victoria Passage marking the western entrance to Carnley Harbour, which extends away to the southeast.

Figure 5. Light-based geolocation data logger attached to the leg of a white-capped albatross using a custom-designed leg band.

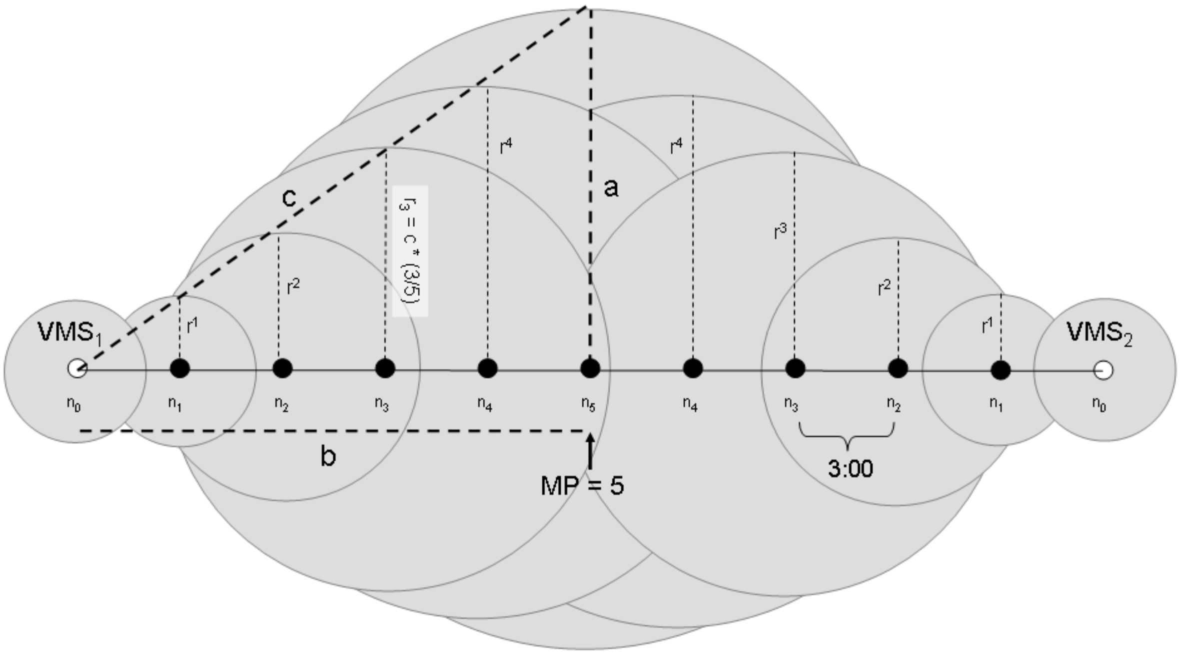


Figure 6. Schematic illustration of calculation of radii (r^i) for spatial buffers around two consecutive VMS points (VMS$_1$ and VMS$_2$), represented by white circles. Black circles are generated points at 3 minute intervals (n_i). *a*, the radius of the mid-point spatial buffer, is calculated based on the Pythagorean theorem and the values of *c* (½ eD) and *b* (MP * dR). Radii of other spatial buffers calculated as a proportion of *a* based on distance from VMS point. (See text and Appendix 1 for explanation).

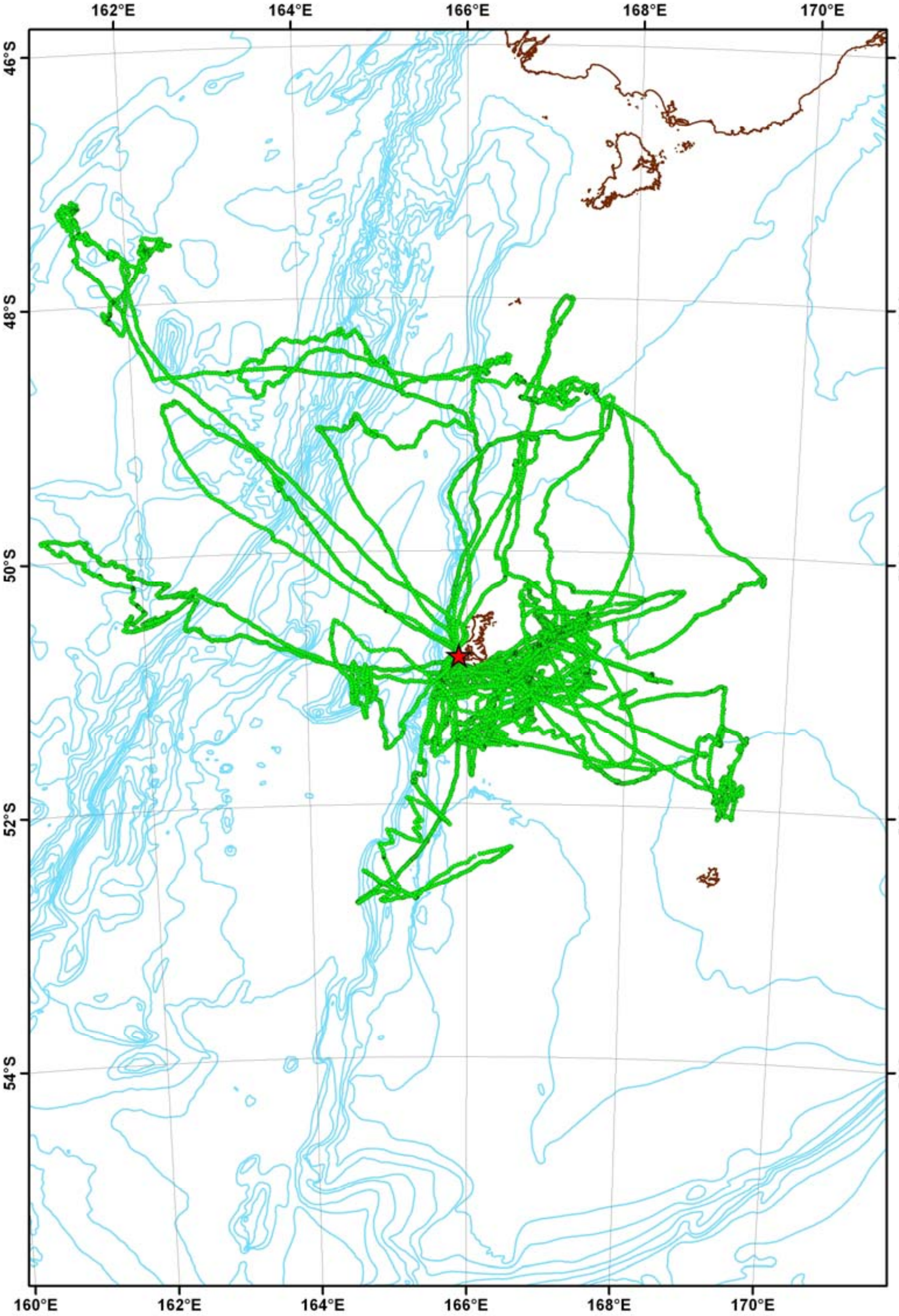


Figure 7. Plot showing all GPS tracks from white-capped albatross during the guard stage in 2005-06. The red star shows the location of South West Cape, and bathymetric contours are at 500 m intervals to 7,000 m.

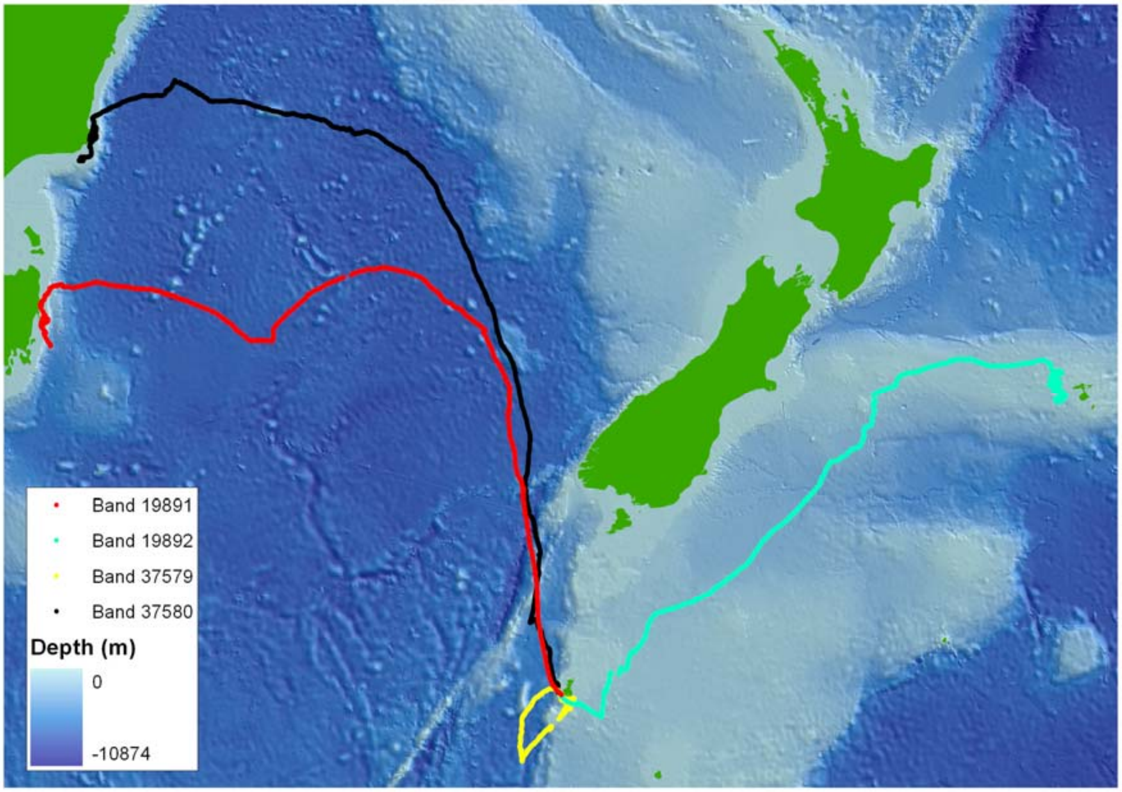


Figure 8. Map showing the GPS tracks from four white-capped albatross during the incubation phase 2007-08.

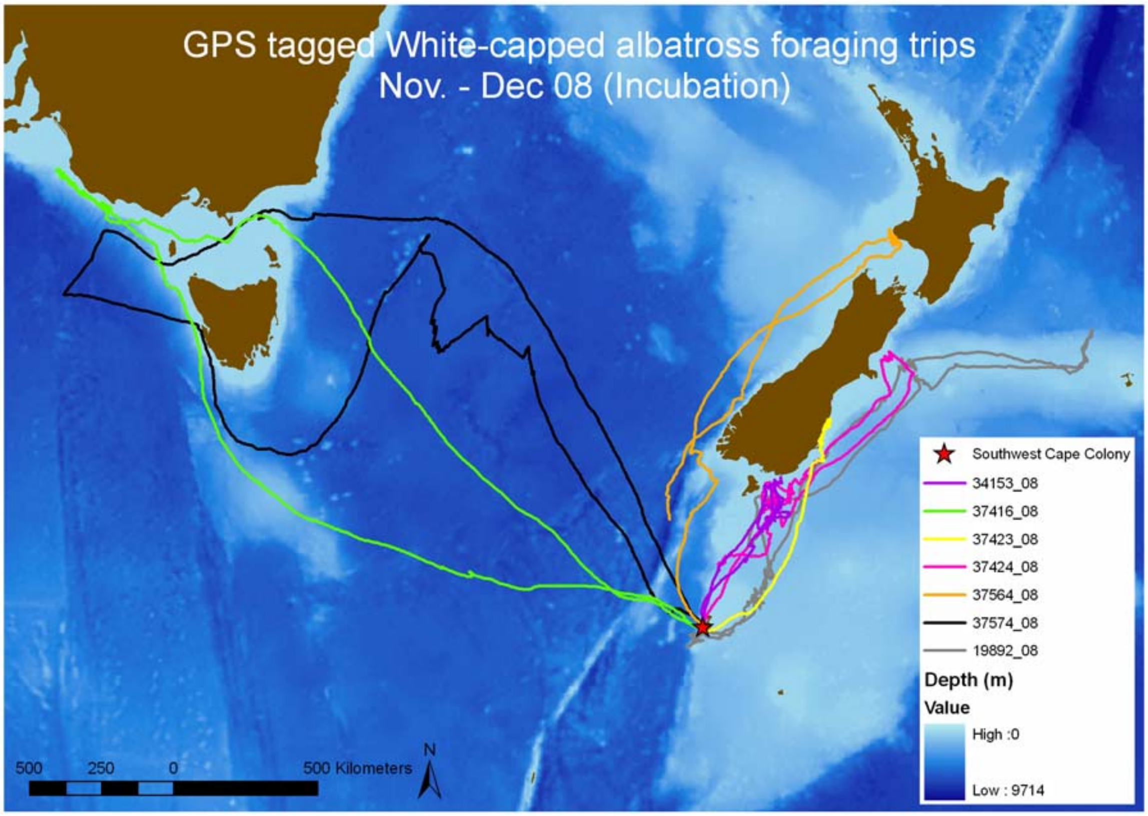


Figure 9. Map showing the GPS tracks from seven white-capped albatross during the incubation phase 2008-09.

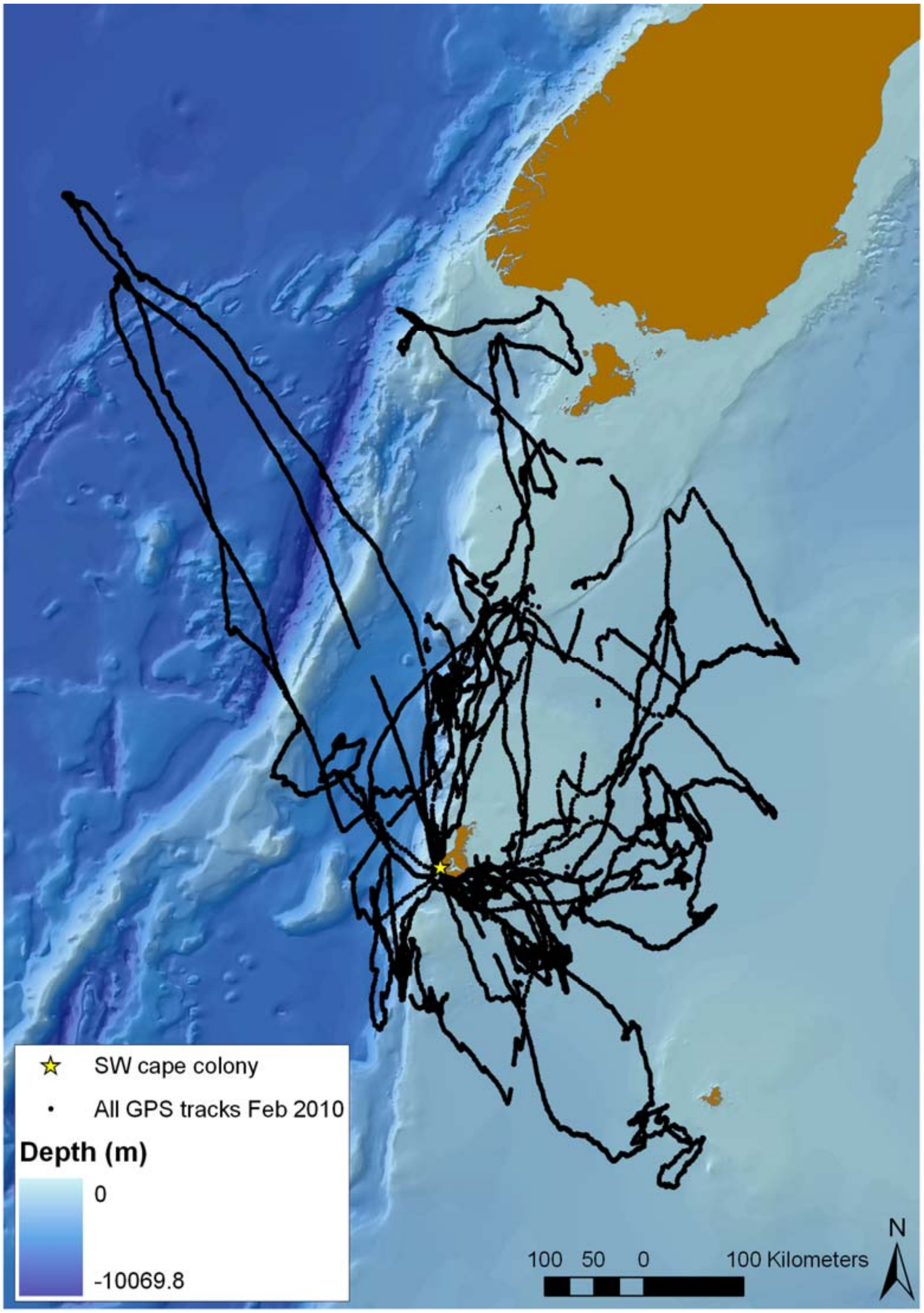


Figure 10. Map showing the GPS tracks from 18 white-capped albatross during the guard stage 2009-10. Gaps in the tracks are due to tag malfunction.

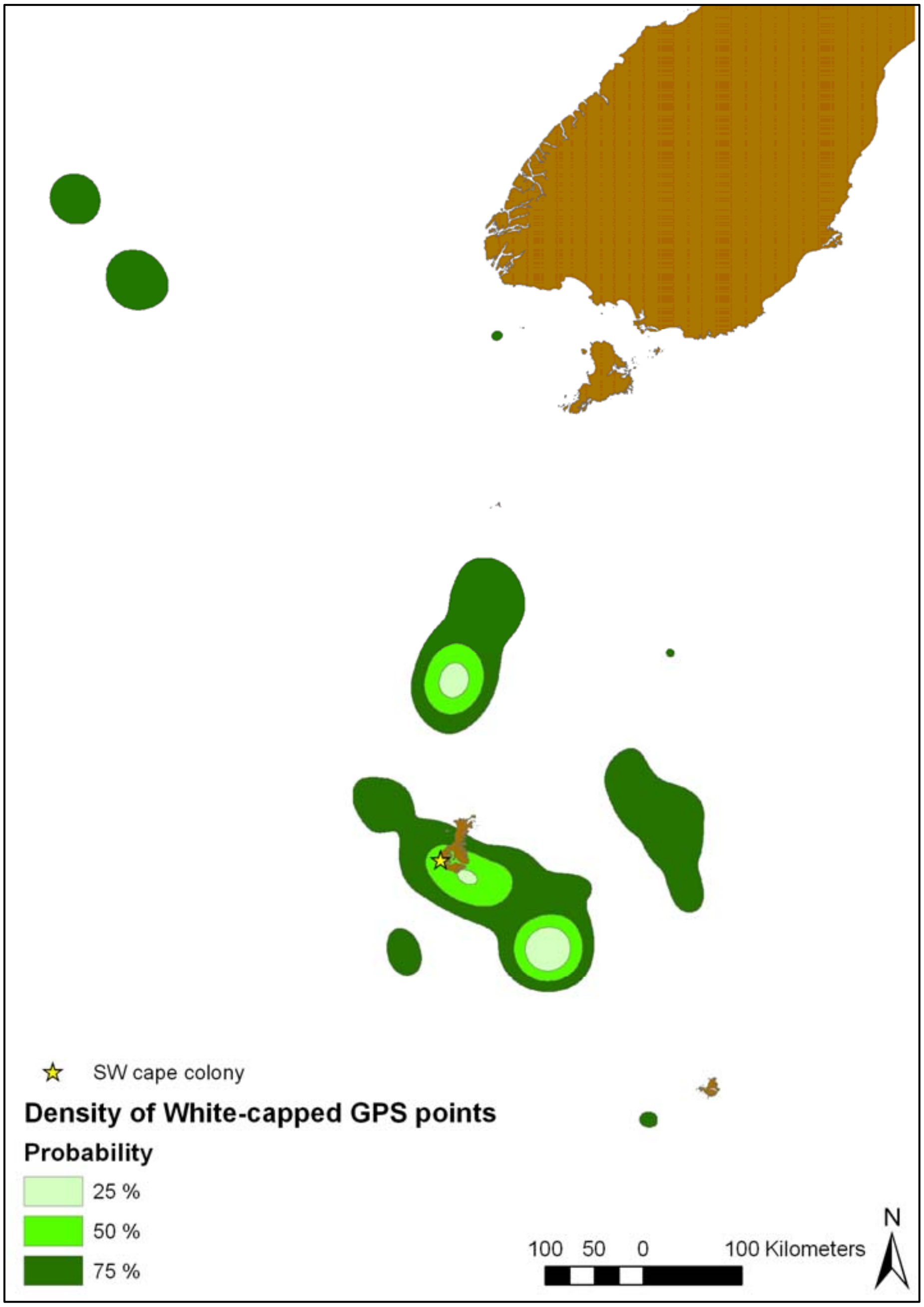


Figure 11. Kernel density plot of GPS locations of white-capped albatross during the guard stage 2009-10.

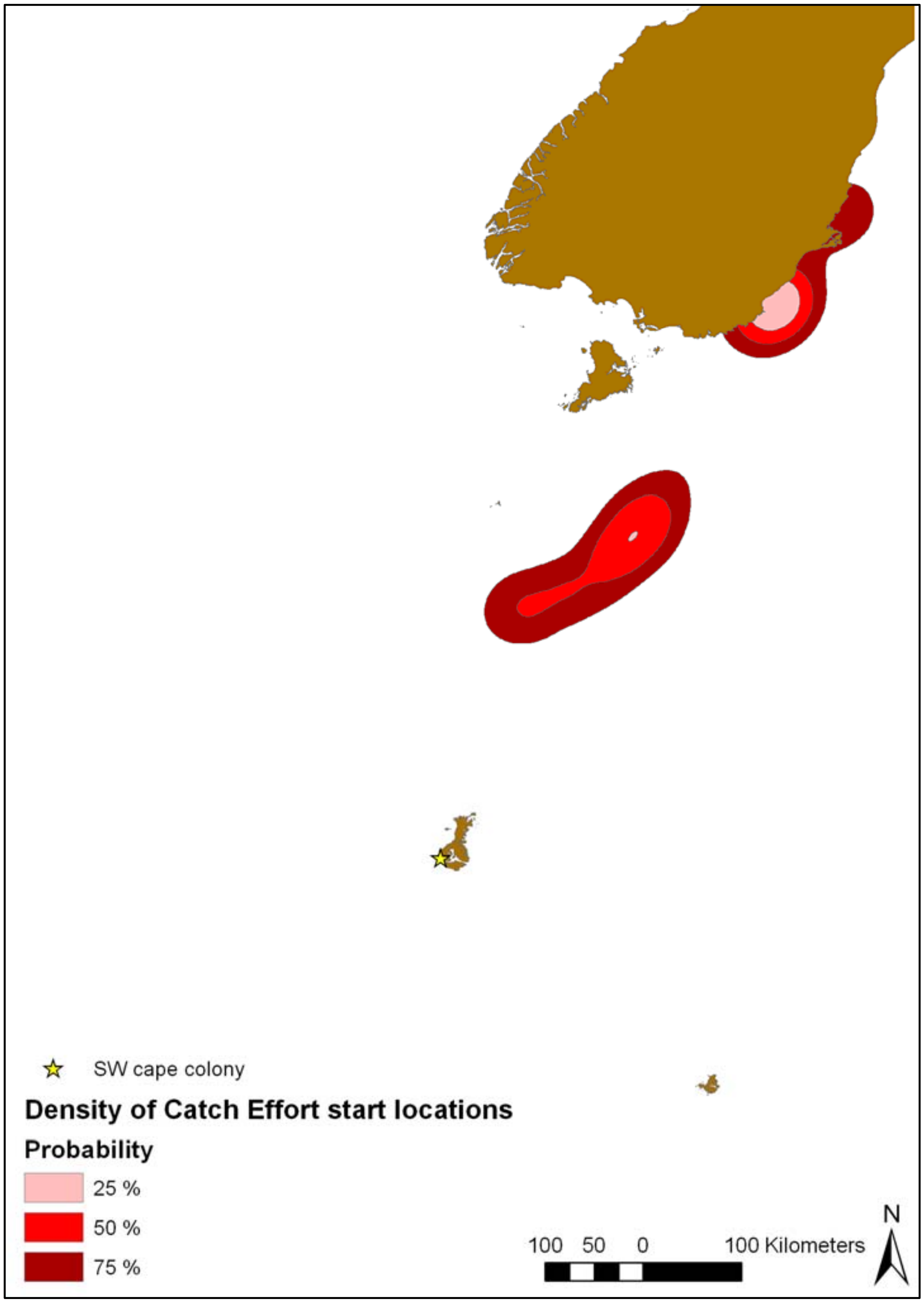


Figure 12. Kernel density plot of fishing events, primarily trawl events targeting squid, during the same temporal window that white-capped albatross were tracked using GPS tags, guard stage 2009-10.

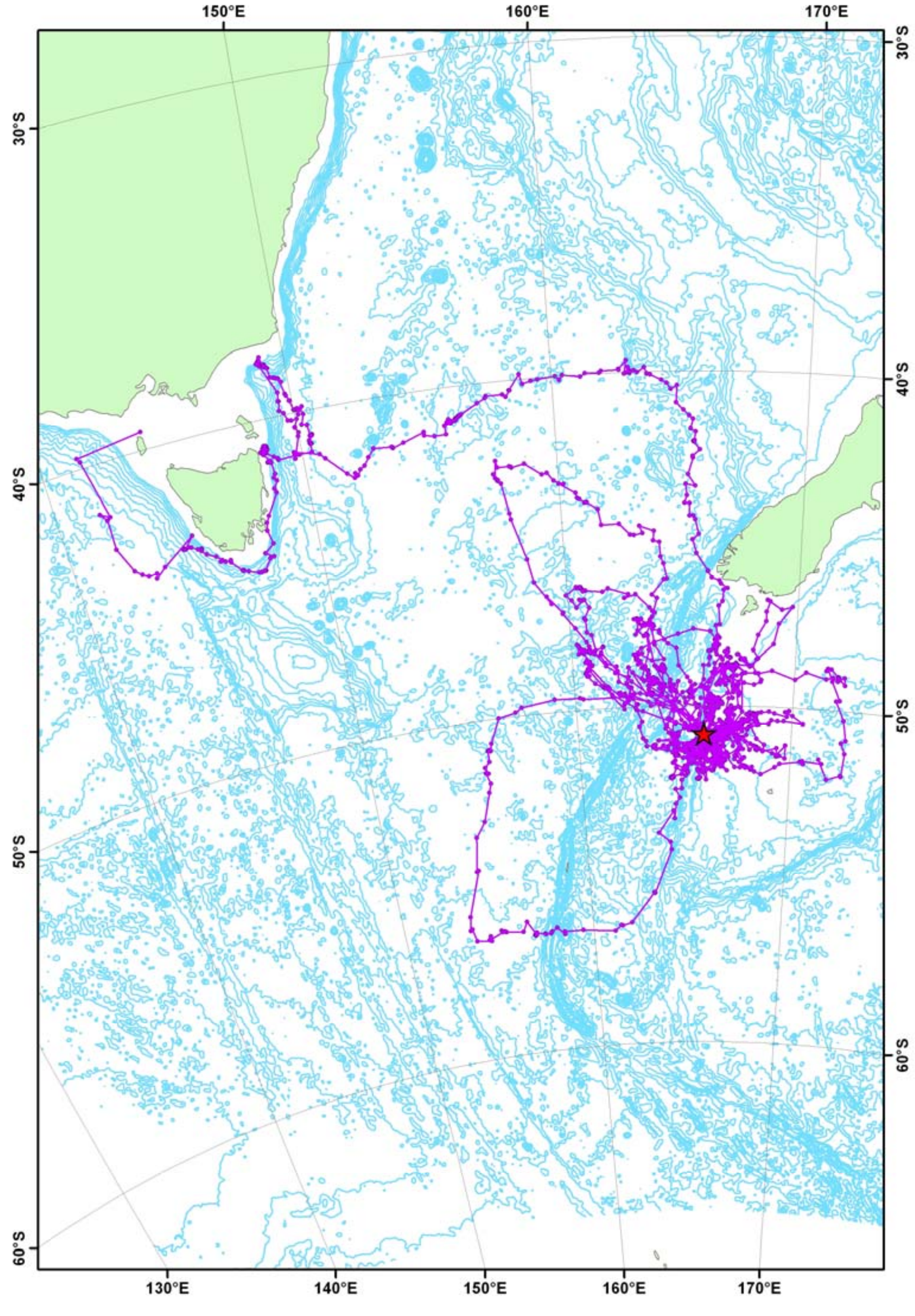


Figure 13. Map showing all filtered PTT fixes and routes from the guards stage 2005-06. The red star shows the location of South West Cape, and bathymetric contours are at 500 m intervals to 7,000 m. Birds are assumed to travel in straight lines between two accepted locations.

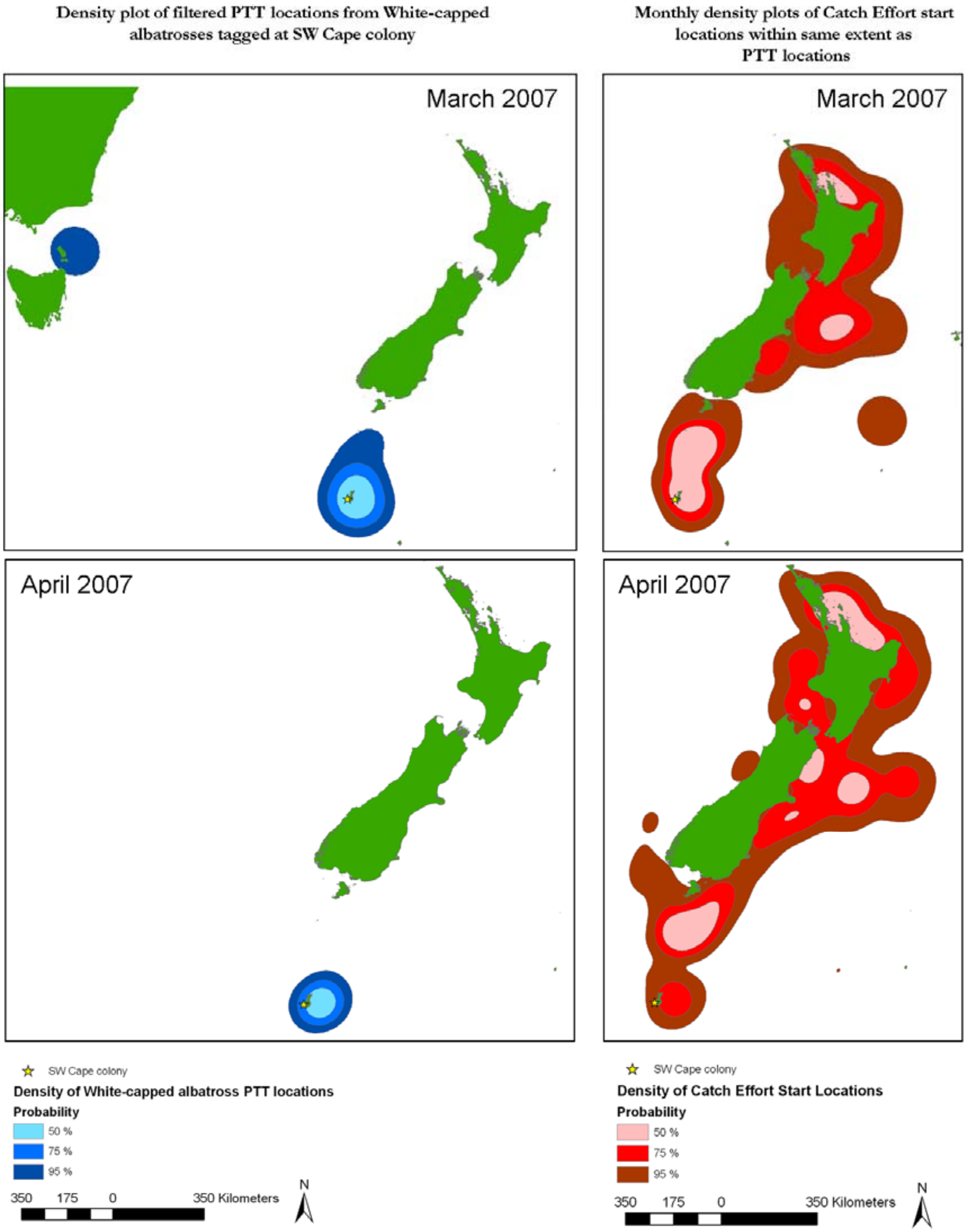


Figure 14. Kernel density plots of PTT data and fishing event data for part of the chick-rearing stage 2006-07.

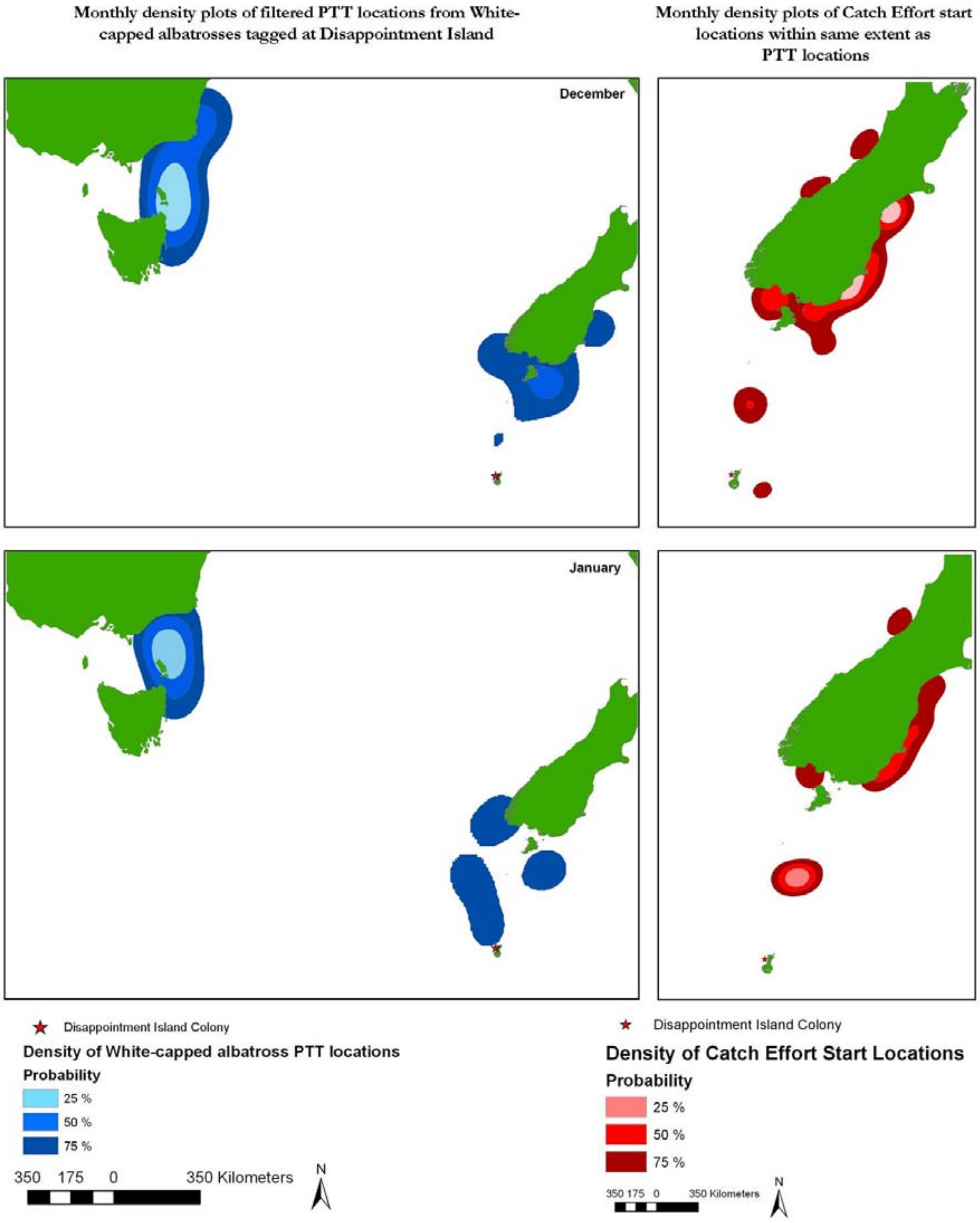


Figure 15. Kernel density plots of PTT data from birds at Disappointment Island and fishing event data for December and January 2008-09.

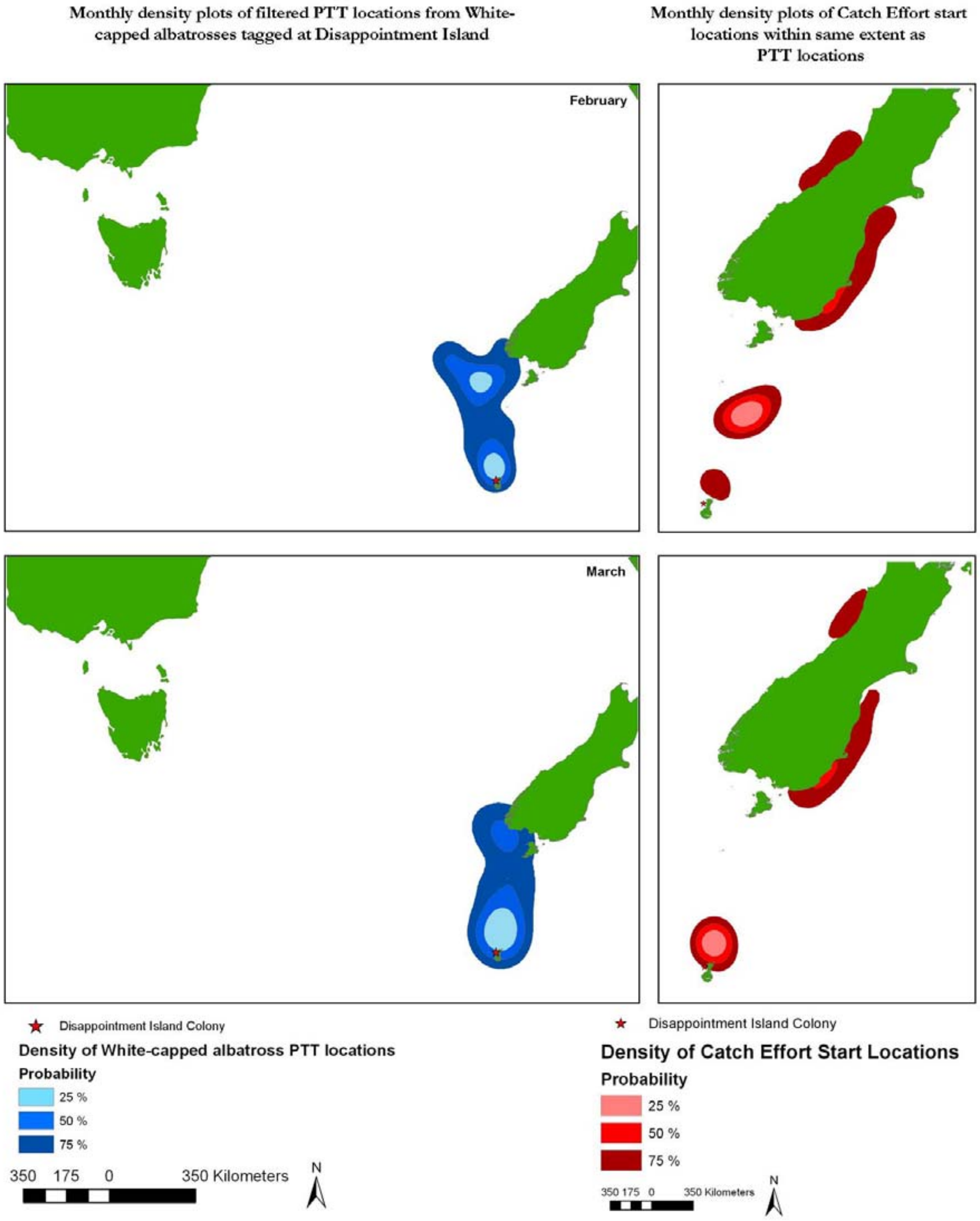


Figure 16. Kernel density plots of PTT data from birds at Disappointment Island and fishing event data for February and March 2009.

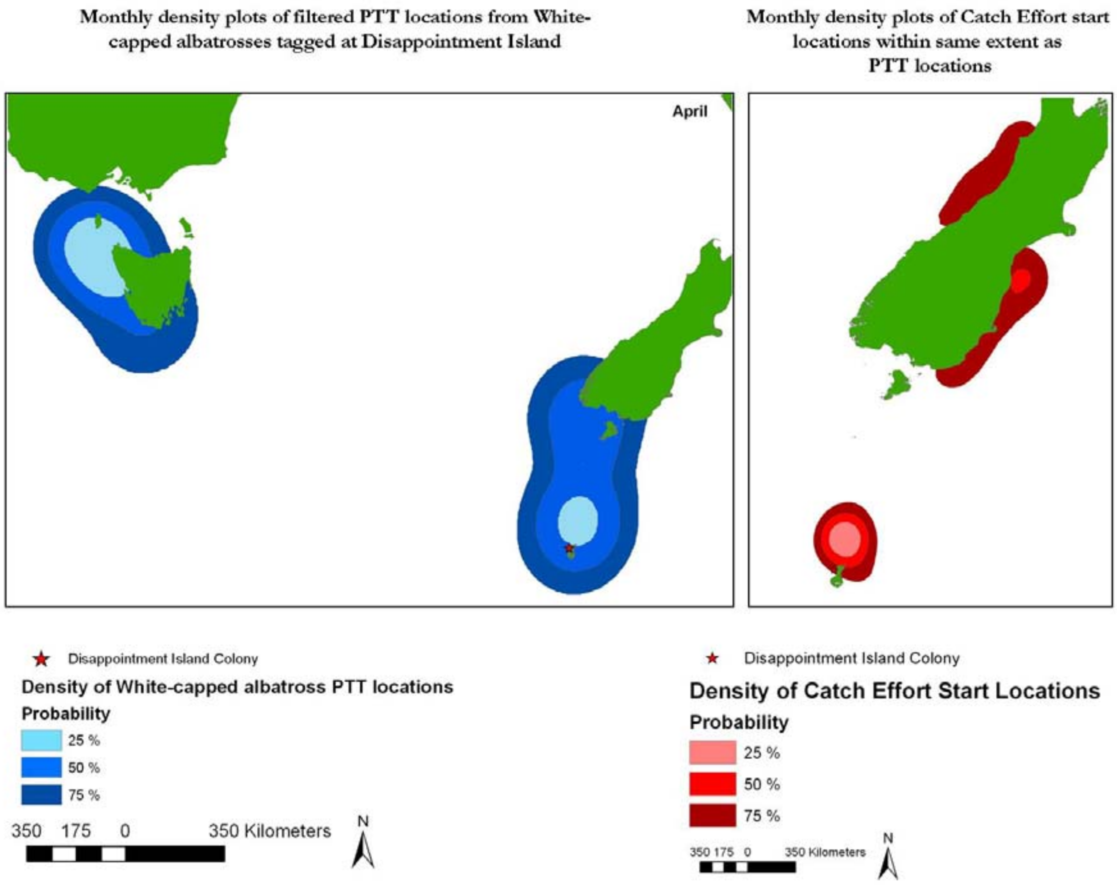


Figure 17. Kernel density plots of PTT data from birds at Disappointment Island and fishing event data for April 2009.

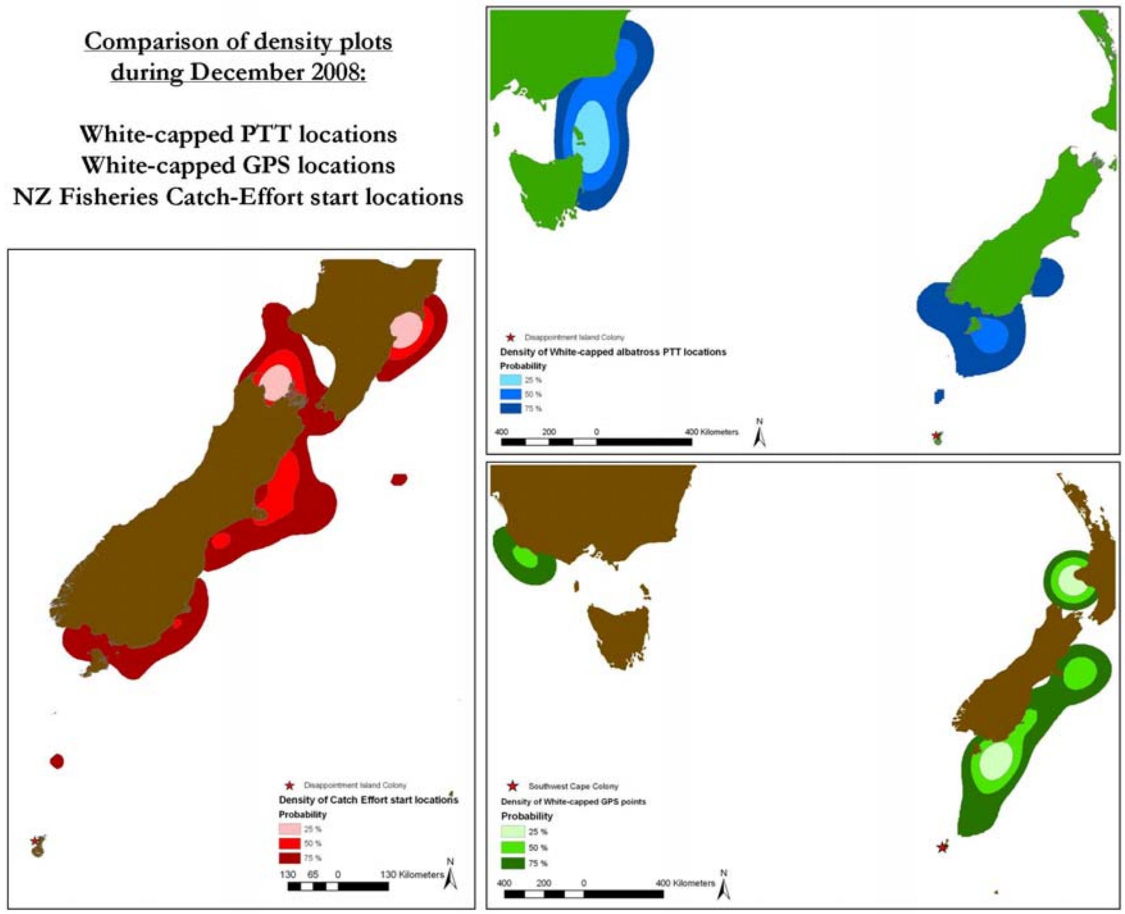


Figure 18. Kernel density plots for PTT data from birds at Disappointment Island, GPS data from birds at South West Cape and fishing event data for December 2008.

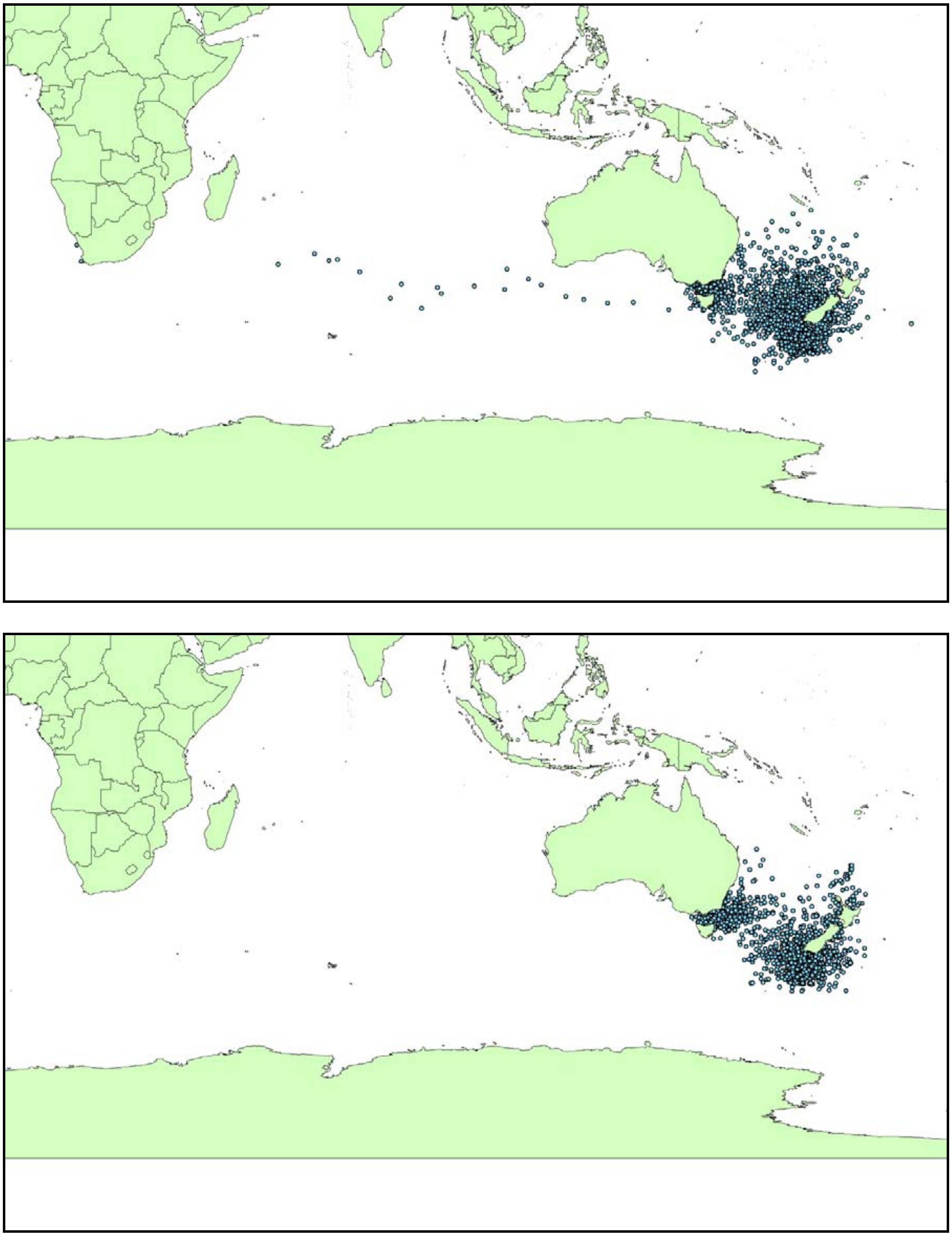


Figure 19. White-capped albatross distributions, derived from light-based geolocation tags, during November-January (incubation): breeding birds (upper) and non-breeding birds (lower).

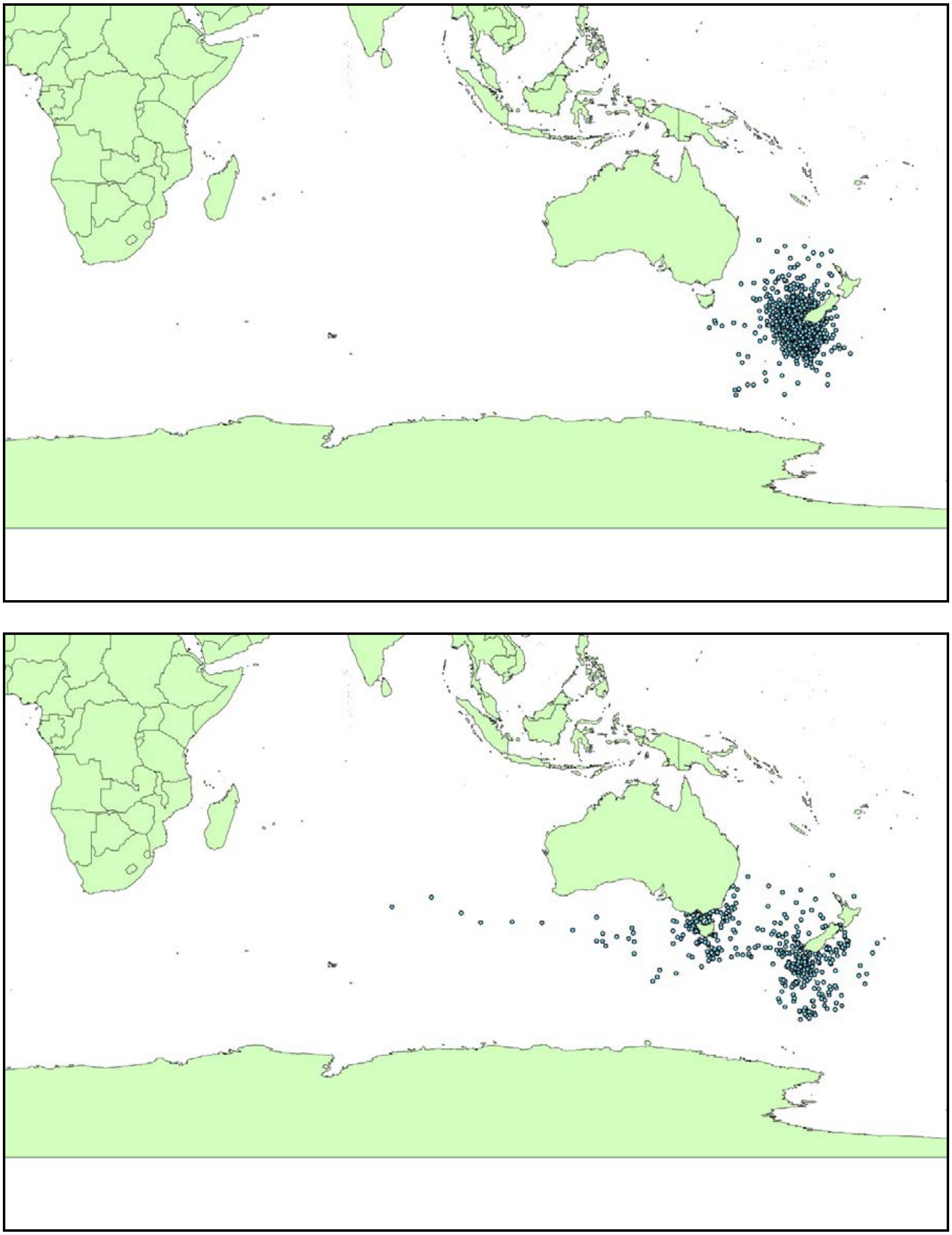


Figure 20. White-capped albatross distributions, derived from light-based geolocation tags, during February (guard): breeding birds (upper) and non-breeding birds (lower).

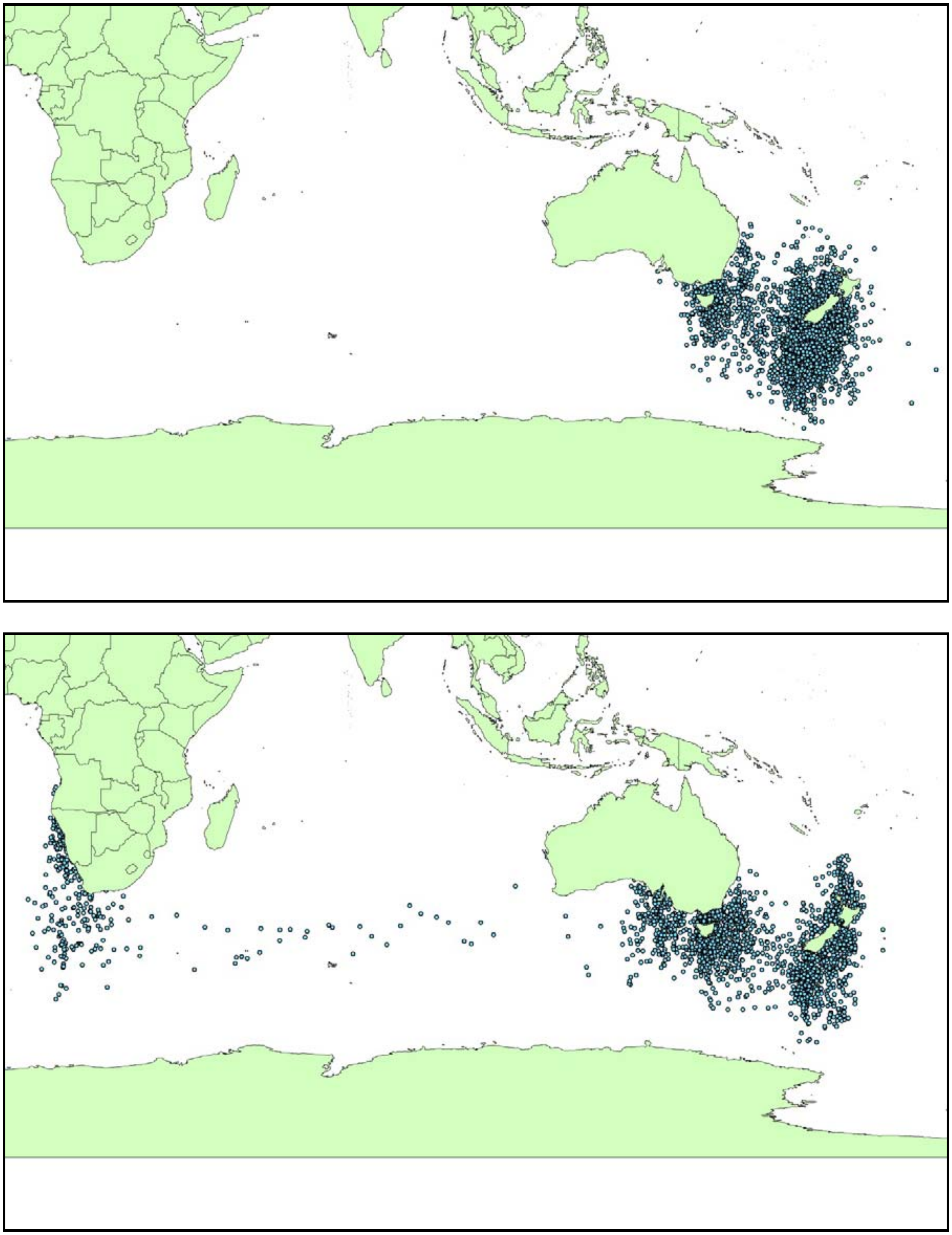


Figure 21. White-capped albatross distributions, derived from light-based geolocation tags, during March-June (chick-rearing): breeding birds (upper) and non-breeding birds (lower).

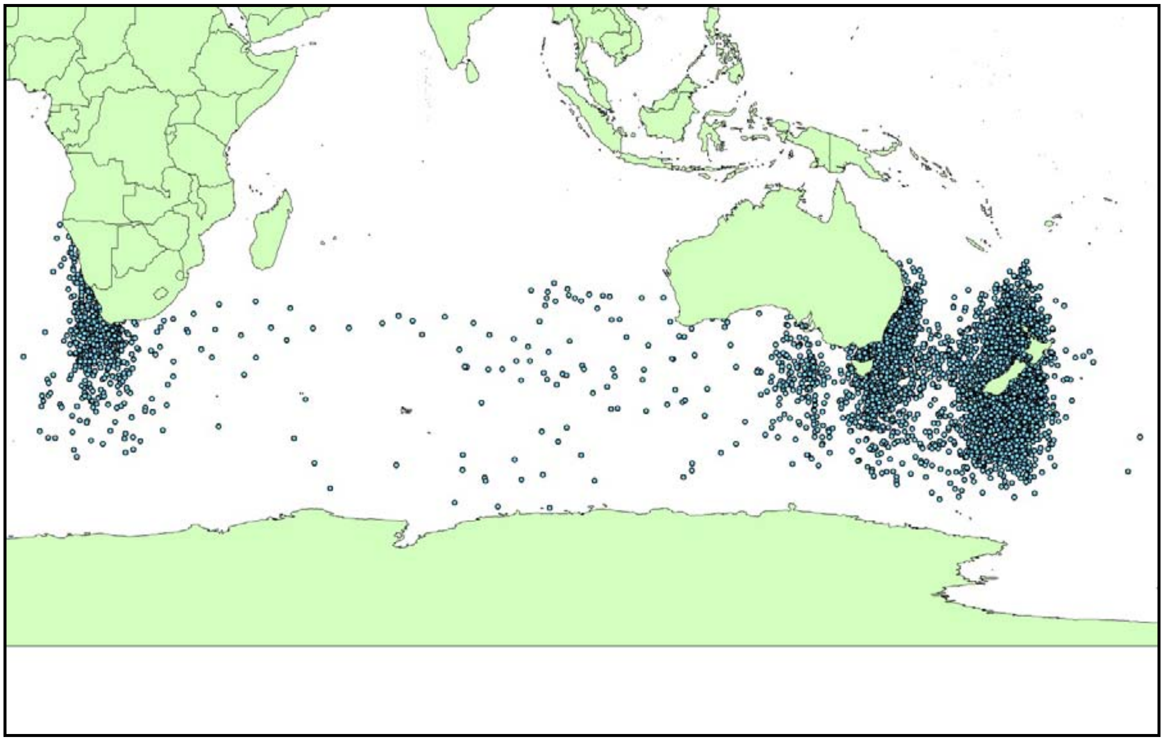


Figure 22. White-capped albatross distribution, derived from light-based geolocation tags, during July-October (non-breeding period: all birds combined).

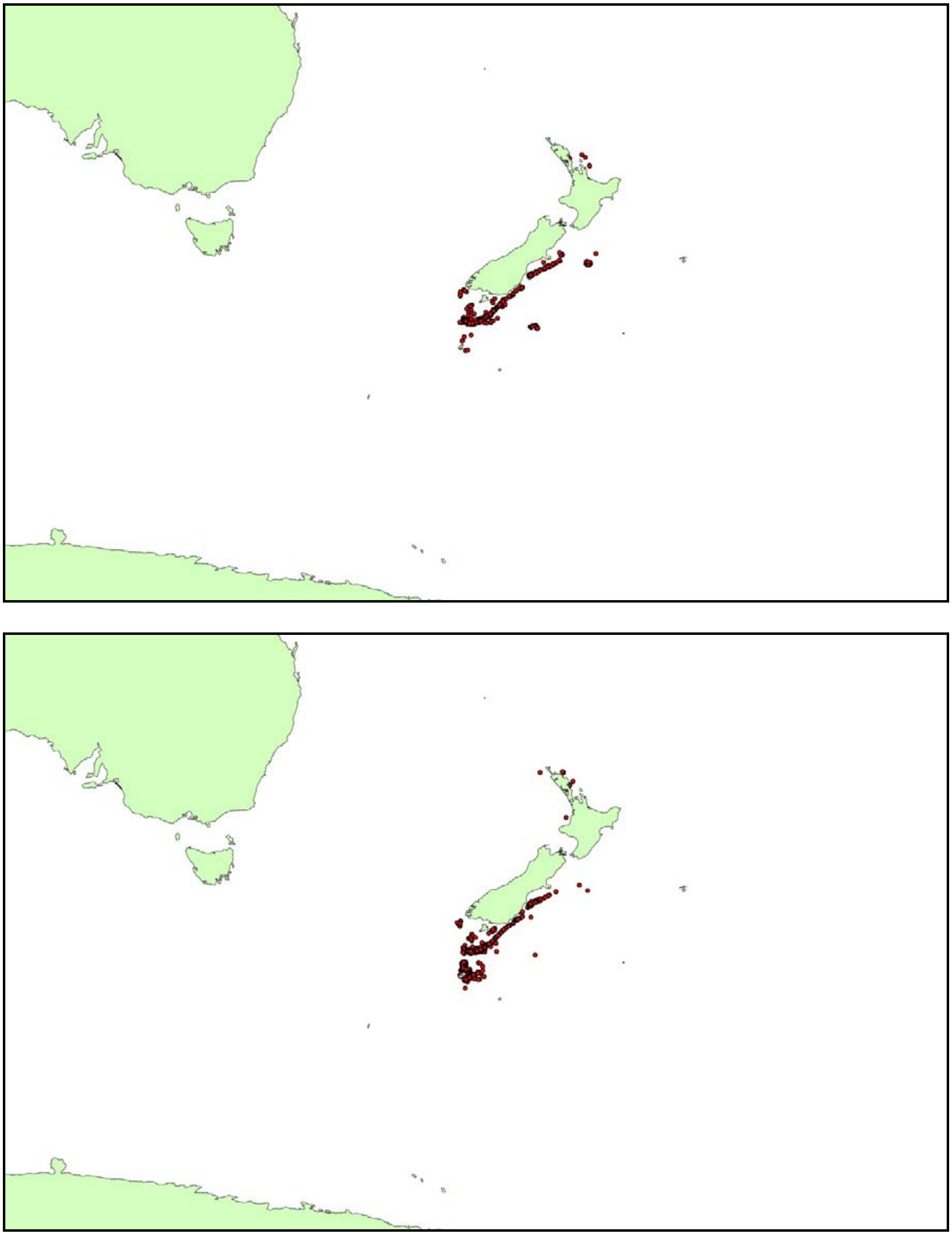


Figure 23. Fishing effort distributions for vessels targeting squid during incubation (upper, November to January) and guard (lower, February) stages of white-capped albatross breeding cycle.

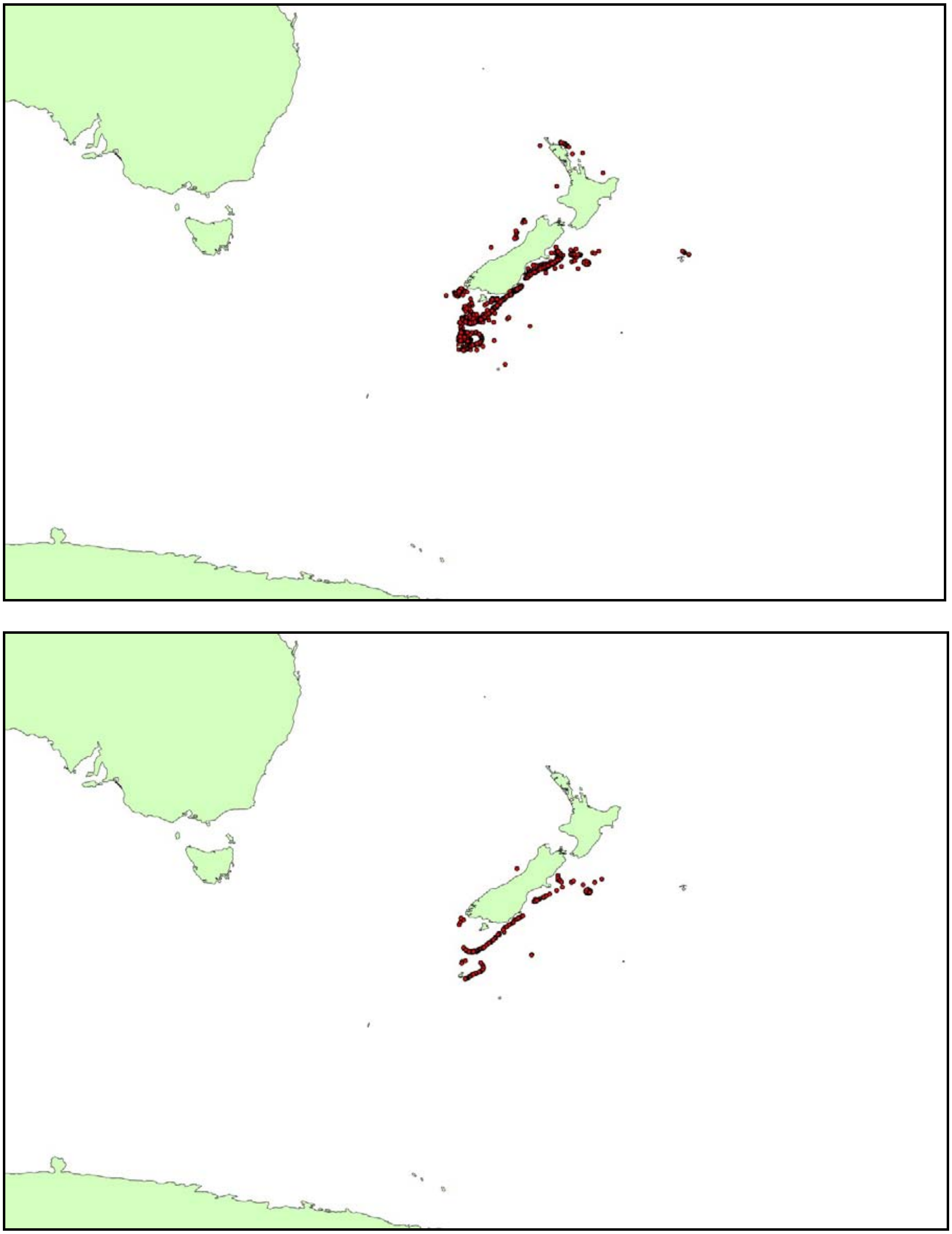
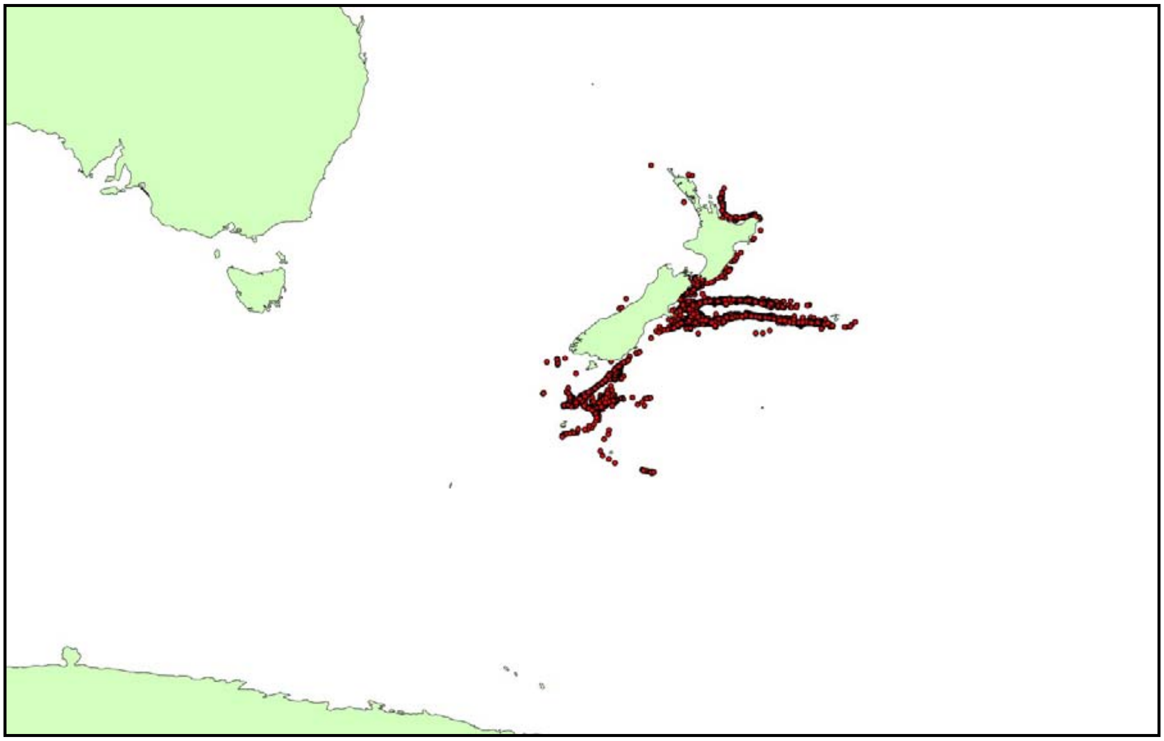


Figure 24. Fishing effort distributions for vessels targeting squid during chick-rearing (upper, March to June) and non-breeding (lower, July-October) stages of white-capped albatross breeding cycle.



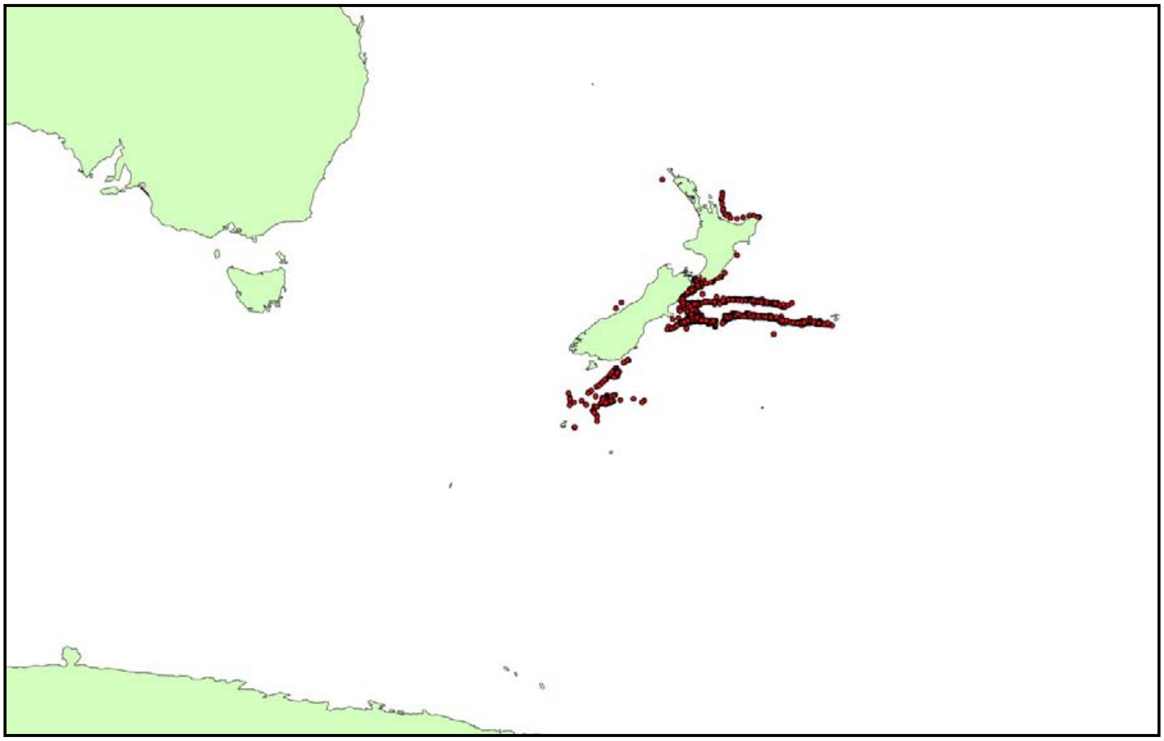


Figure 25. Fishing effort distributions for vessels targeting hoki during incubation (upper, November to January) and guard (lower, February) stages of white-capped albatross breeding cycle.

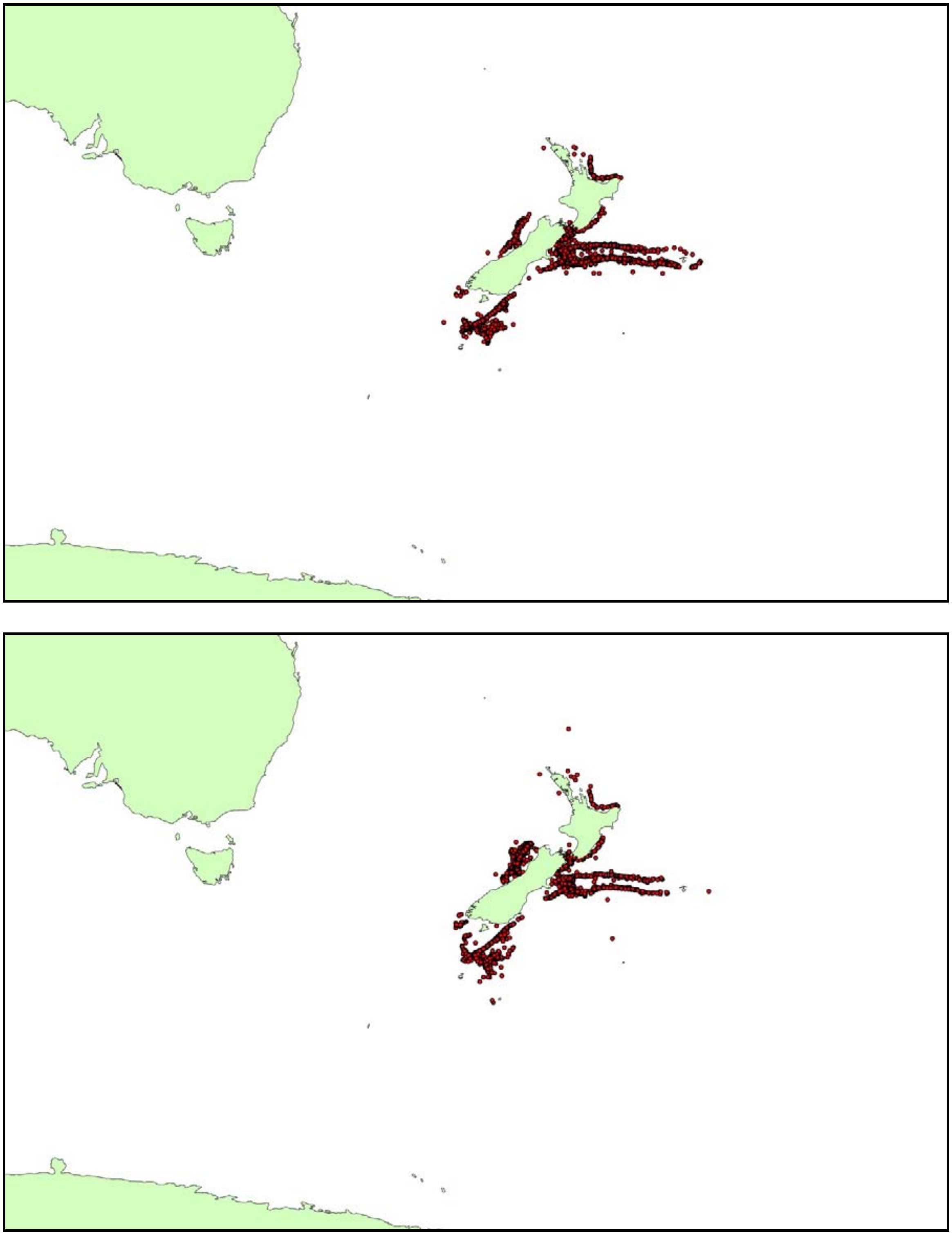


Figure 26. Fishing effort distributions for vessels targeting hoki during chick-rearing (upper, March to June) and non-breeding (lower, July-October) stages of white-capped albatross breeding cycle.

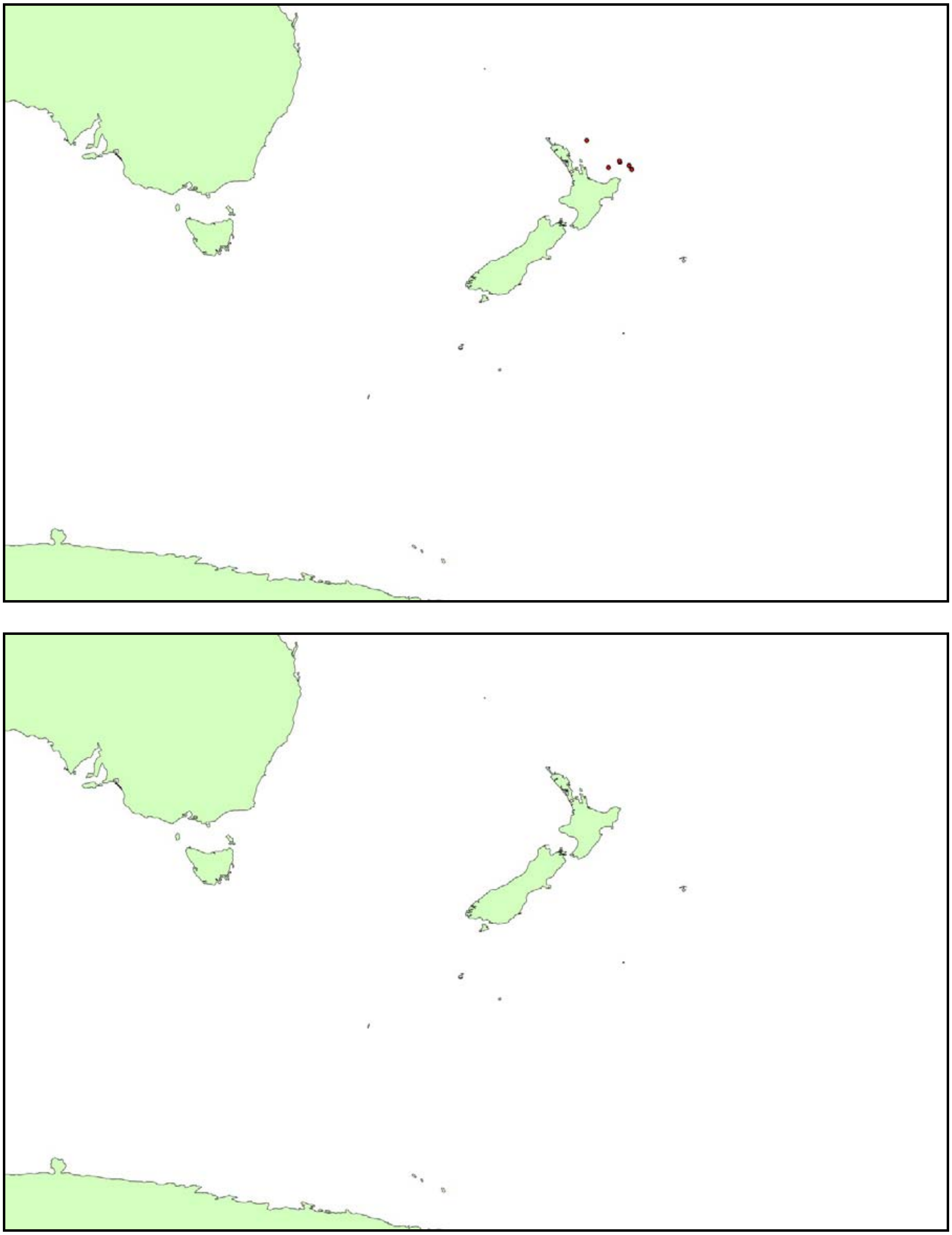


Figure 27. Fishing effort distributions for vessels targeting southern bluefin tuna during incubation (upper, November to January) and guard (lower, February) stages of white-capped albatross breeding cycle.

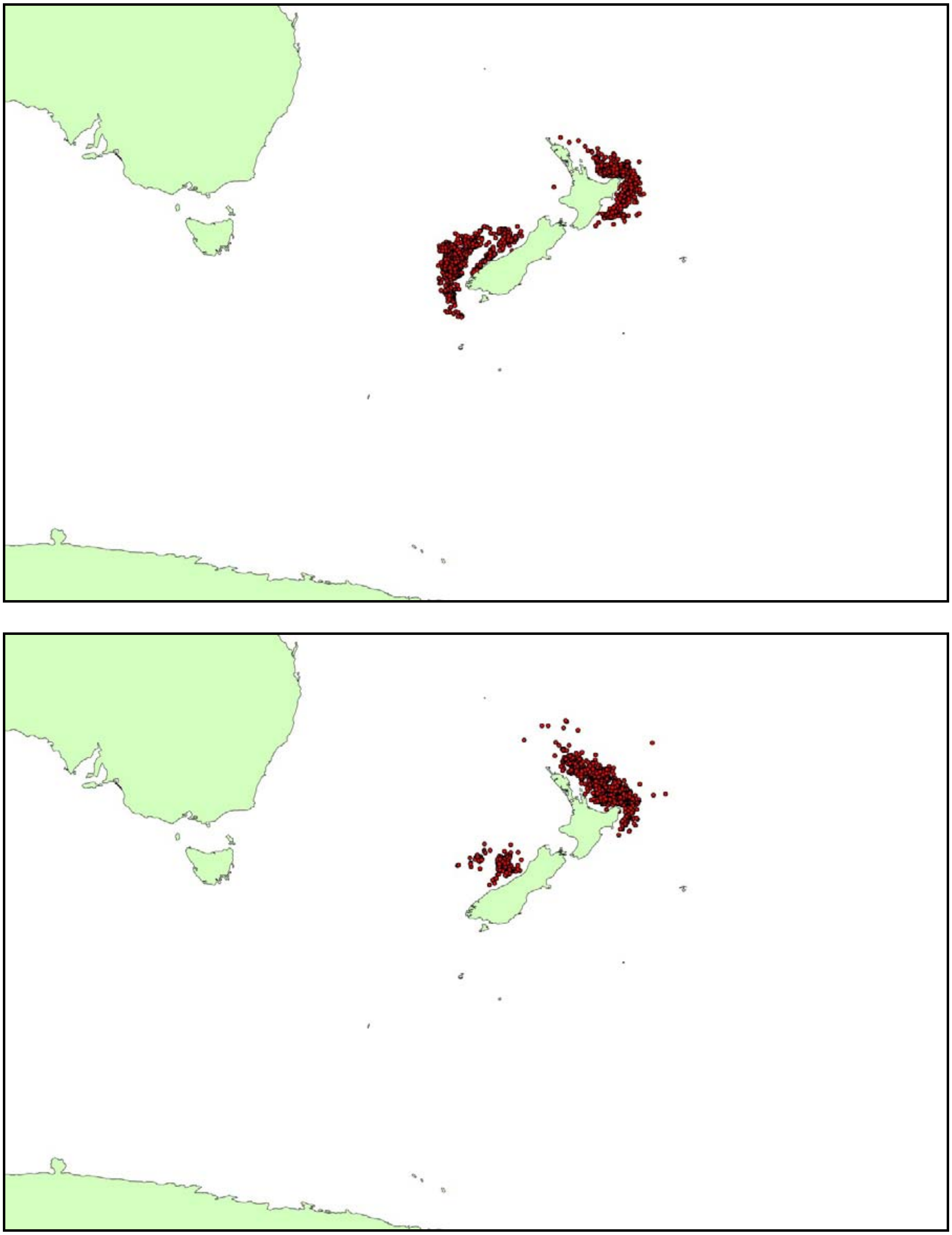


Figure 28. Fishing effort distributions for vessels targeting southern bluefin tuna during chick-rearing (upper, March to June) and non-breeding (lower, July-October) stages of white-capped albatross breeding cycle.

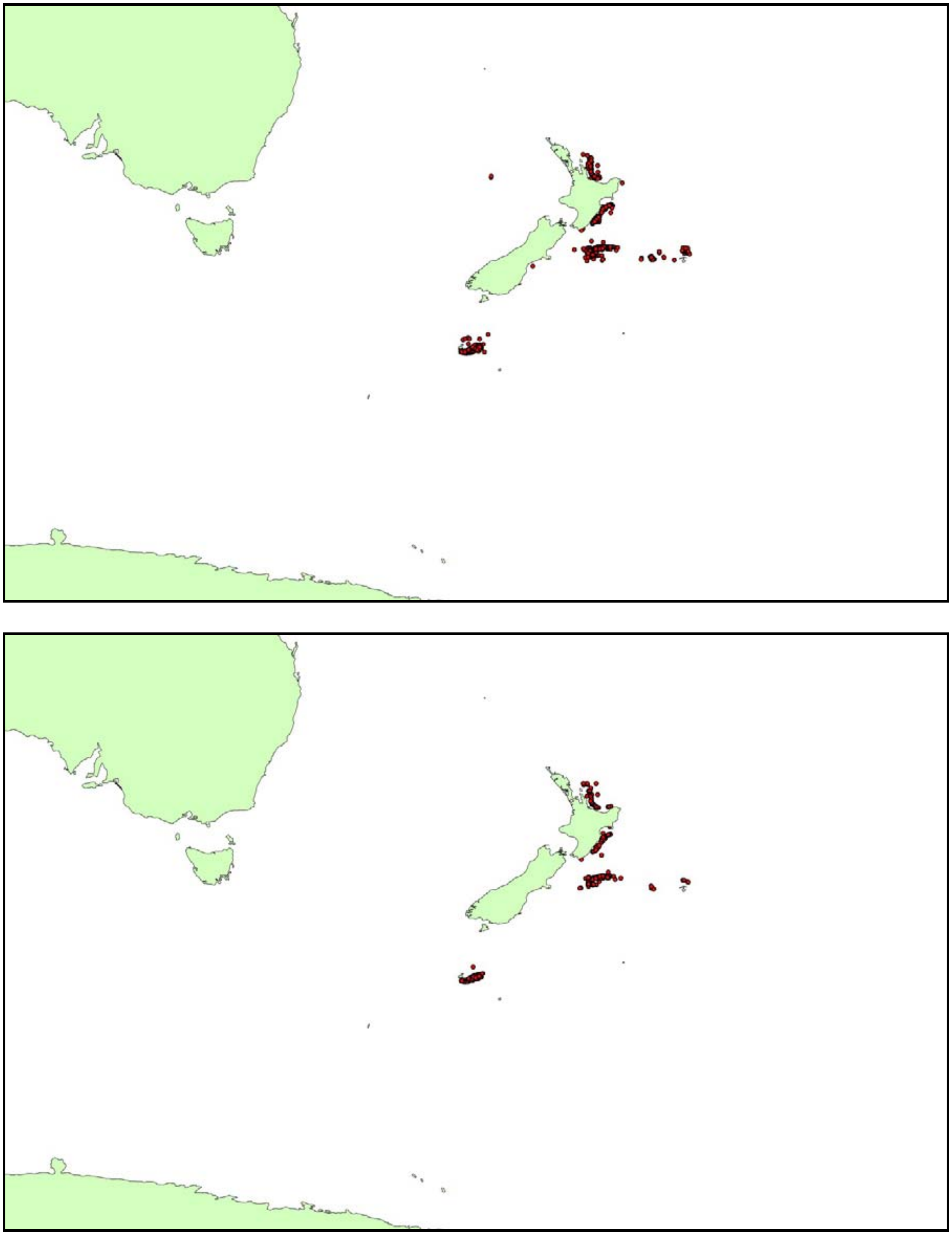
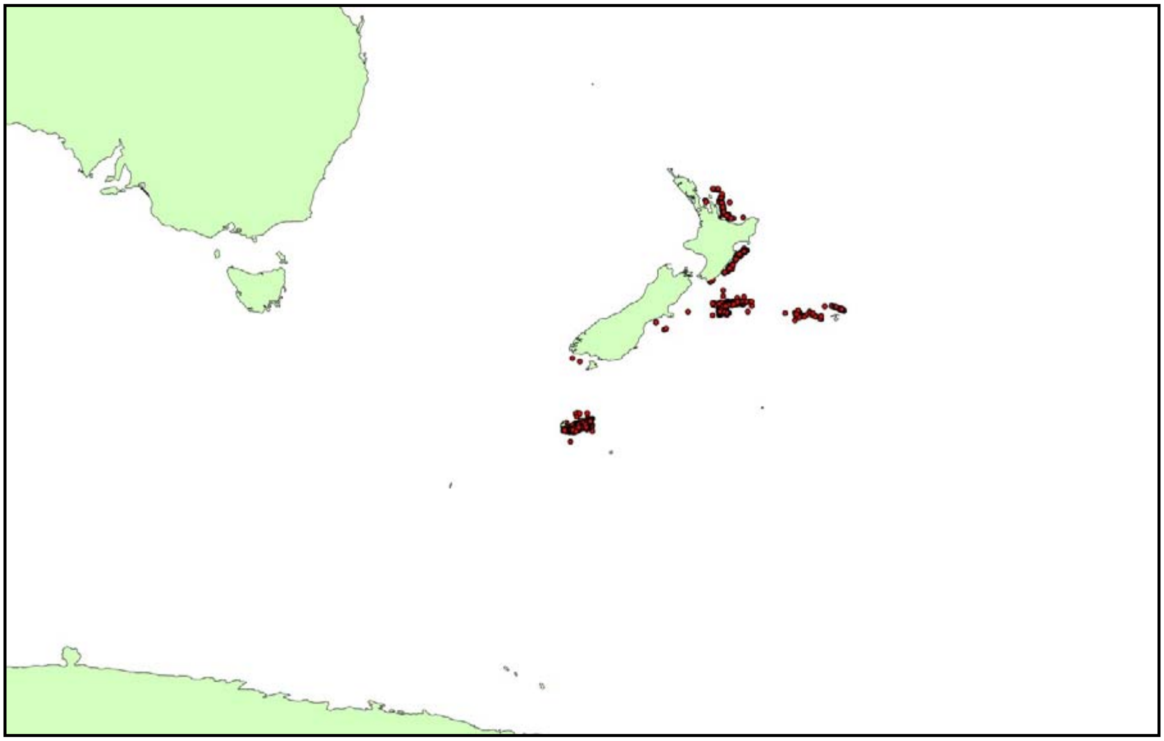


Figure 29. Fishing effort distributions for vessels targeting scampi during incubation (upper, November to January) and guard (lower, February) stages of white-capped albatross breeding cycle.



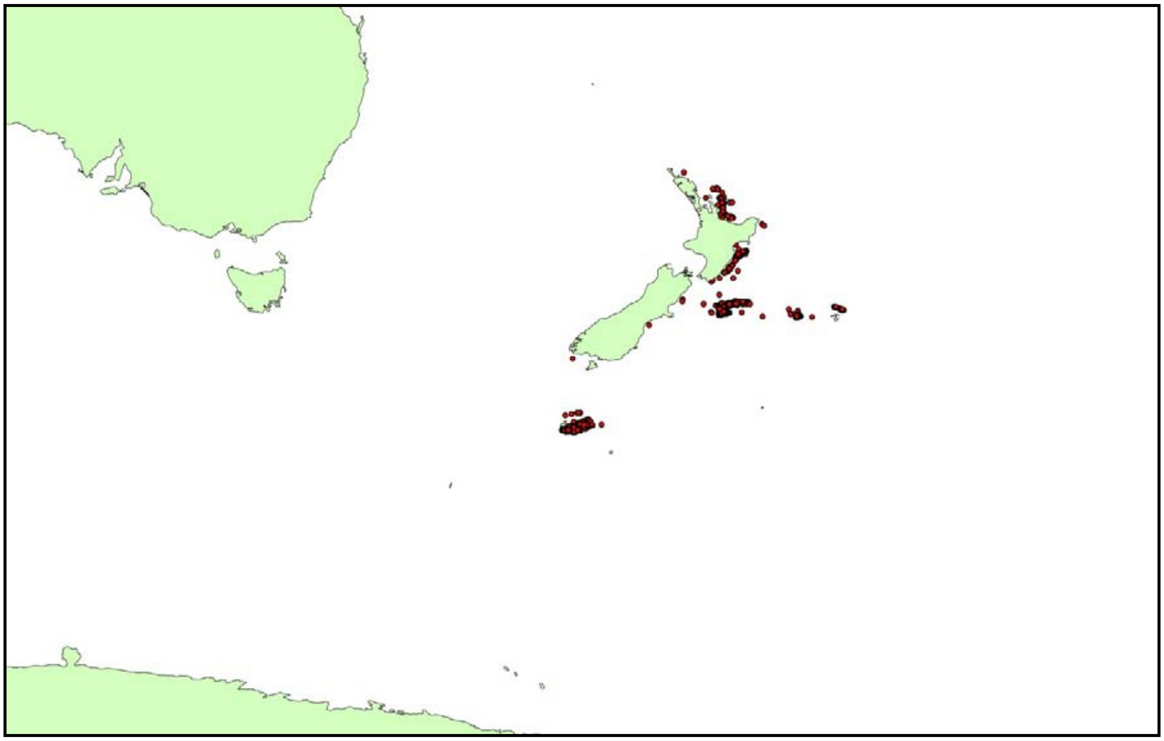


Figure 30. Fishing effort distributions for vessels targeting scampi during chick-rearing (upper, March to June) and non-breeding (lower, July-October) stages of white-capped albatross breeding cycle.

Table 1. Summary of fieldwork visits and work undertaken.

Breeding Season	South West Cape			Disappointment Island
	Incubation	Guard	Chick-rearing	Incubation
2005-06		B GPS PTT GEOd		
2006-07			B R PTT GEOd GEOr	
2007-08	B R GPS GEOd GEOr			
2008-09	B R GPS GEOr			PTT
2009-10		R GPS GEOr		
2010-11*	R GEOr			

B = banding
R = re-sighting of banded birds
GPS = deployment of GPS data-logging tags
PTT = deployment of PTT data-transmitting tags
GEOd = deployment of light-based geolocation tags
GEOr = retrieval of light-based geolocation tags
* = a short (approximately 1 hour), opportunistic visit

Appendix 1.

Full description of methods to identify overlap between albatross GPS points and fishing vessel tracks from VMS data.

Using Matlab (Version 7.6, R2008a, The MathWorks, Inc.), code was written to iteratively perform these steps to determine overlap between each albatross track point and all fishing vessel tracks (See Fig.2 for illustration of methods).

For every pair of consecutive VMS points: VMS_1 and VMS_2
1) Calculate the time length between VMS points: $T = time_2 – time_1$
2) Determine the number of points to be generated in between VMS points: n = T / 3:00
3) Calculate the distance (R) between VMS_1 and VMS_2
4) Calculate average vessel speed between VMS_1 and VMS_2 based on speed stamps at the two VMS points: $S = speed_1 + speed_2 / 2$
5) Determine the length of each segment in between each 3:00 point: dR = R / n
6) Calculate the maximum potential distance (pD) the vessel could have travelled: pD = S * T
7) Calculate the excess distance (eD) that the vessel did not travel due to turning, slowing, etc.: eD = pD - R
8) Determine the mid-point (MP) between the two consecutive VMS points (VMS_1 and VMS_2). This is the point that will have the largest spatial buffer because it has the maximum uncertainty of the vessel’s location. MP = rounded down to the nearest integer (n / 2)
9) Determine the radius (a) of the spatial buffer at MP using the Pythagorean theorem, where
c = eD / 2
b = MP * dR
a = square root ($c^2 + b^2$)
10) Based on a, the buffer radius (r^i) for each 3 minute point (n_i) is calculated:
Buffer radius for point n_i = (a * (n_i/MP))

For n_0 (same as VMS_1 and VMS_2): Buffer radius = dR. Small radius buffers were applied to these points (actual VMS positions) because an albatross is unlikely to have the exact same position as a vessel's VMS transponder, but rather be within a couple 100s of meters.

If there was an even number of generated 3:00 points (n), then the last point before VMS_2 has a buffer radius = dR.

11) If $pD < R$ for any vessel track (the average speed was slower than the actual speed needed to get from n_1 to n_2) than the limit distance (lD) was calculated: $lD = R – pD$.

½ lD was then used as the buffer radius for all 3 minute points along these tracks. This scenario was infrequent.

12) All points along each albatross track were evaluated to identify those points which fell within the created spatial radius buffers and within a ±3 minute temporal window of the VMS point or generated 3 minute intervals along the vessel tracks.