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First satellite tracks of the Endangered black-capped petrel

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ABSTRACT: The black-capped petrel *Pterodroma hasitata* is an endangered seabird with fewer than 2000 breeding pairs restricted to a few breeding sites in Haiti and the Dominican Republic. To date, use areas at sea have been determined entirely from vessel-based surveys and opportunistic sightings and, as such, spatial and temporal gaps in our understanding of the species' marine range are likely. To enhance our understanding of marine use areas, we deployed satellite tags on 3 black-capped petrels breeding on Hispaniola, representing the first tracking study for this species and one of the first published tracking studies for any breeding seabird in the Caribbean. During chick rearing, petrels primarily used marine habitats in the southern Caribbean Sea (ca. 18.0° to 11.5° N, 70.0° to 75.5° W) between the breeding site and the coasts of Venezuela and Colombia. Maximum distance from the breeding sites ranged from ca. 500 to 1500 km during the chick-rearing period. During the post-breeding period, each bird dispersed north and used waters west of the Gulf Stream offshore of the mid- and southern Atlantic coasts of the USA as well as Gulf Stream waters and deeper pelagic waters east of the Gulf Stream. Maximum distance from the breeding sites ranged from ca. 2000 to 2200 km among birds during the nonbreeding period. Petrels used waters located within 14 different exclusive economic zones, suggesting that international collaboration will benefit the development of management strategies for this species.

KEY WORDS: Black-capped petrel · *Pterodroma hasitata* · Satellite telemetry · Migration · Caribbean Sea · Western North Atlantic Ocean

INTRODUCTION

One of the most effective means to inform assessment of threats to seabirds away from breeding sites is to define their spatial and temporal use areas at sea. In the western North Atlantic, marine spatial data for Procellariiformes, as well as most other seabirds, have been obtained primarily through ship-based surveys, particularly south of ca. 35° N (O'Connell et al. 2009). At-sea surveys have the advantage of targeting all species and age classes of seabirds for specific locations at specific times and can be particularly effective at obtaining repeated measures from a site of interest. However, such surveys tend not to cover all areas of the ocean; often cannot distinguish age, sex, or breeding status; and fail to explicitly link breeding sites to marine locations. In the western North Atlantic, this has resulted in gaps in our understanding of at-sea use of seabirds particularly in the South Atlantic Bight and the Caribbean, where ship-

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based surveys have been less common (O'Connell et al. 2009, Jodice et al. 2013).

The western North Atlantic historically supported 3 breeding species of gadfly petrels *Pterodroma* spp. The Jamaican petrel *Pterodroma caribbaea* is likely extinct, last observed in 1879 (Douglas 2000). The cahow *P. cahow,* also known as the Bermuda petrel, is limited to ca. 100 pairs breeding on 4 small islets around Bermuda (Madeiros 2012). The black-capped petrel *P. hasitata*, also known as the diablotín, is estimated to have <2000 breeding pairs and is listed as Endangered on the IUCN Red List (BirdLife International 2015). The species is confirmed to breed at Macaya, Massif de la Selle, and Sierra de Bahoruco on Hispaniola Island and is suspected to breed at 2 additional sites in the Dominican Republic and 1 site in Cuba (Simons et al. 2013), and radar surveys in 2015 in Dominica resulted in hundreds of detections of black-capped petrels (A. Brown unpubl. data). Our understanding of marine habitat use for both the cahow and black-capped petrel has primarily been limited to data gathered from surveys and opportunistic observations at sea, which are not balanced in time or space. Recently, geolocators have been used to investigate use areas and movement patterns of the cahow (Madeiros 2012). Here, we report on the first tracking efforts for the black-capped petrel. Our study sought to obtain novel data on movement patterns between breeding and foraging sites, foraging trip duration during the breeding season, and migration routes and wintering use areas. A more thorough and complex habitat modeling approach will follow.

MATERIALS AND METHODS

We deployed 3 satellite tags on breeding petrels at Loma del Toro on the Sierra de Bahoruco ridge where nesting has been confirmed (Fig. 1). The site is ca. 22 km inland and 1900 to 2300 m in elevation and is characterized by steep slopes and ridges with forests of Hispaniolan pine *Pinus occidentalis* and pockets of mesic broadleaf. Since 2010, ca. 45 nest burrows have been discovered sparsely distributed across 7 km of this ridge. The nesting area is under pressure from timber harvest, charcoal making, agricultural encroachment, and forest fires. Lighted cell phone towers atop the ridge attract petrels and may cause light-induced mortality (Le Corre et al. 2002).

Traps were set prior to sunset in burrows with evidence of nesting activity and checked at first light. We constructed traps (ca. 0.5 m long with an opening ca. 25 by 25 cm) from fine mesh wire with a 1-way door. Solar-powered satellite tags weighing 9.5 g (North Star Science and Technology) were attached to birds along the upper back, central to the birds' body mass, using 4 subcutaneous sutures (Ethicon Prolene, 45 cm length, 2-0, FS reverse cutting, 26 mm 3/8 cm) and a small amount of glue (Loctite 422). Satellite tags had suture channels running across the width of the tag base to facilitate attachment. This attachment technique has been used successfully with other gadfly petrels and shearwaters (MacLeod et al. 2008, Ronconi et al. 2010, Reid et al. 2014). The duty cycle of the tags was 8 h on, 24 h off. We measured standard morphometrics and body mass of adults. Chicks were left undisturbed. The handling process lasted 20 min, and birds were then returned to the burrow. Prior to leaving the nest site, we also

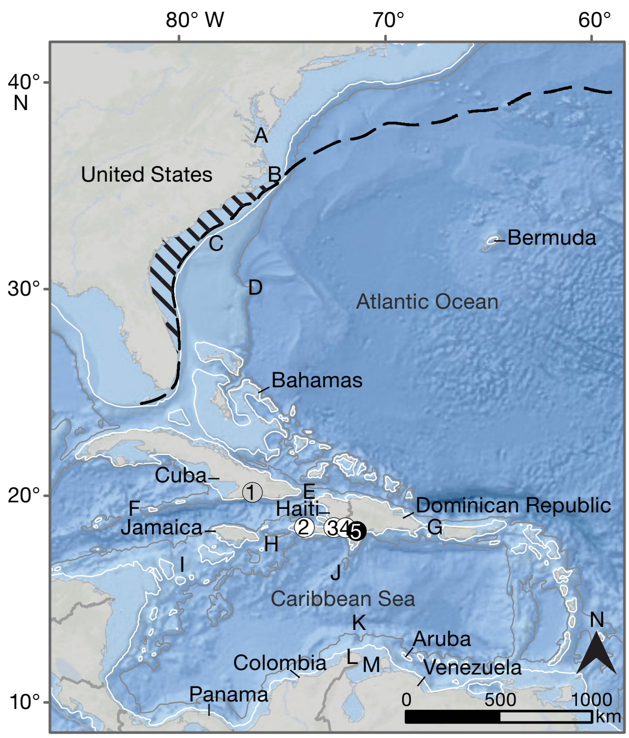

Fig. 1. *Pterodroma hasitata.* Study area. Circles with numbers indicate breeding colonies (grey: suspected breeding; white: confirmed breeding; black: study colony). 1: Sierra Maestra, Cuba; 2: Pic Macaya, Haiti; 3: Pic La Visite, Haiti; 4: Morne Vincent, Haiti; 5: Sierra de Bahoruco, Dominican Republic. Letters indicate geographic and oceanographic features. A: Chesapeake Bay; B: Cape Hatteras; C: Charleston Bump; D: Blake Spur; E: Windward Passage; F: Cayman Ridge; G: Mona Passage; H: Albatross Bank; I: Nicaragua Rise; J: Beata Ridge; K: Aruba Gap; L: Guajira Peninsula; M: Gulf of Venezuela. Dashed line estimates the western edge of the Gulf Stream for April to October 2014. Solid lines indicate bathymetry: 200 m (white) and 2000 m (grey). Dashed area indicates the South Atlantic Bight

placed a trail camera (Reconyx PC 800) at each entrance (settings: movement detection = high sensitivity, 10 pictures per trigger, rapid fire, no delay).

All Argos locations were run through a Bayesian state space model (package bsam, Jonsen et al. 2013) to improve the accuracy of location estimates and evenness of the sampling interval (Reid et al. 2014). All Argos location classes were used as model inputs. Nest visits by tagged birds (n = 9, confirmed by time-stamped image on trail camera of arrival [n = 2], departure [n = 5], or both arrival and departure [n = 2] from nest) were included as fixed locations and anchored some trips to the breeding site during the nesting season. The modeling approach uses a Markov chain Monte Carlo method and ran 20 000 iterations (thinned by every 20th record) after a burn-in of 80 000 iterations to eliminate the effects of initial values. The model provided hourly locations for each individual, but due to long 'off' periods of 24 h, it is unrealistic to assume an even accuracy of location estimates between these periods. We therefore filtered the modeled locations to include only those that occurred within 2 h of any Argos location, hence eliminating data with high uncertainty during 'off' periods but retaining an even sampling of higher-accuracy locations during 'on' periods. We classified all locations as breeding or nonbreeding using the camera data to support classifications (i.e. images of parents entering or leaving the nest were used to indicate breeding activity and initiation of nonbreeding activity). During breeding, we segmented each track into separate foraging trips based on visual assessment of the data and images from trail cameras.

RESULTS

Four adult petrels (1 incubating, 3 chick-rearing) were trapped on 8 and 9 April 2014 (Table 1). Feather status of chicks, data from nest checks, and ultimate fate of nests suggested chicks were 1 to 3 wk post hatch. Satellite tags were deployed on the 3 chick-rearing birds. Body mass ranged from 375 to 425 g for the 3 tagged birds, and hence satellite tags ranged from 2.2 to 2.5 % of body mass. Birds were tracked for 136 to 208 d, resulting in 488 bird-tracking days (Table 2). Among all birds, 45 % of locations were accurate to <1500 m, and 90 % were obtained with 4 satellite messages (Table 2). The mean and SD latitude for locations with 4 messages was 23.1 ± 8.5° and for locations with <4 messages it was 25.3 ± 7.7°.

Table 1. Morphometrics and nest status of 4 black-capped petrels *Pterodroma hasitata* captured at Sierra de Bahoruco, Dominican Republic, 8 and 9 April 2014. na = not applicable

Band	Satellite ID	Mass (g)	Wing chord length (mm)	Tarsus length (mm)	Head + bill length (mm)	Culmen length (mm)	Gonys depth (mm)	Nest status
1633-02638	176	425	291	38.2	78.3	32.5	13.4	Chick/fledged
1633-02639	na	335	291	39.5	77.6	30.5	12.8	Egg/failed
1633-02640	177	375	293	39.8	79.7	31.8	13.6	Chick/failed[a]
1633-02641	175	395	294	40.1	78.4	33.1	13.0	Chick/fledged

[a]Due to burrow collapse

Table 2. Total count and accuracy of satellite tag locations based on Argos location classes (LC) of 3 black-capped petrels *Pterodroma hasitata*. LC 0, 1, 2, and 3 indicate the location was obtained with 4 (or more) messages and provides accuracy estimates of better than 250 m (LC 3), better than 500 m (LC 2), better than 1500 m (LC 1), and >1500 m (LC 0). LC A/B indicates the location was obtained with 3 or 2 messages, respectively, and hence no accuracy estimates are available. Birds were tagged on 8 and 9 April 2014

Bird ID	No. of days at liberty	Final transmission	Total no. of locations	LC 3	LC 2	LC 1	LC 0	LC A/B
175	144	30 Aug 2014	323	14	19	89	201	0
176	136	25 Aug 2014	524	14	64	156	211	79
177	208	4 Nov 2014	794	55	143	188	322	87
Total	488		1642	83	226	433	734	166

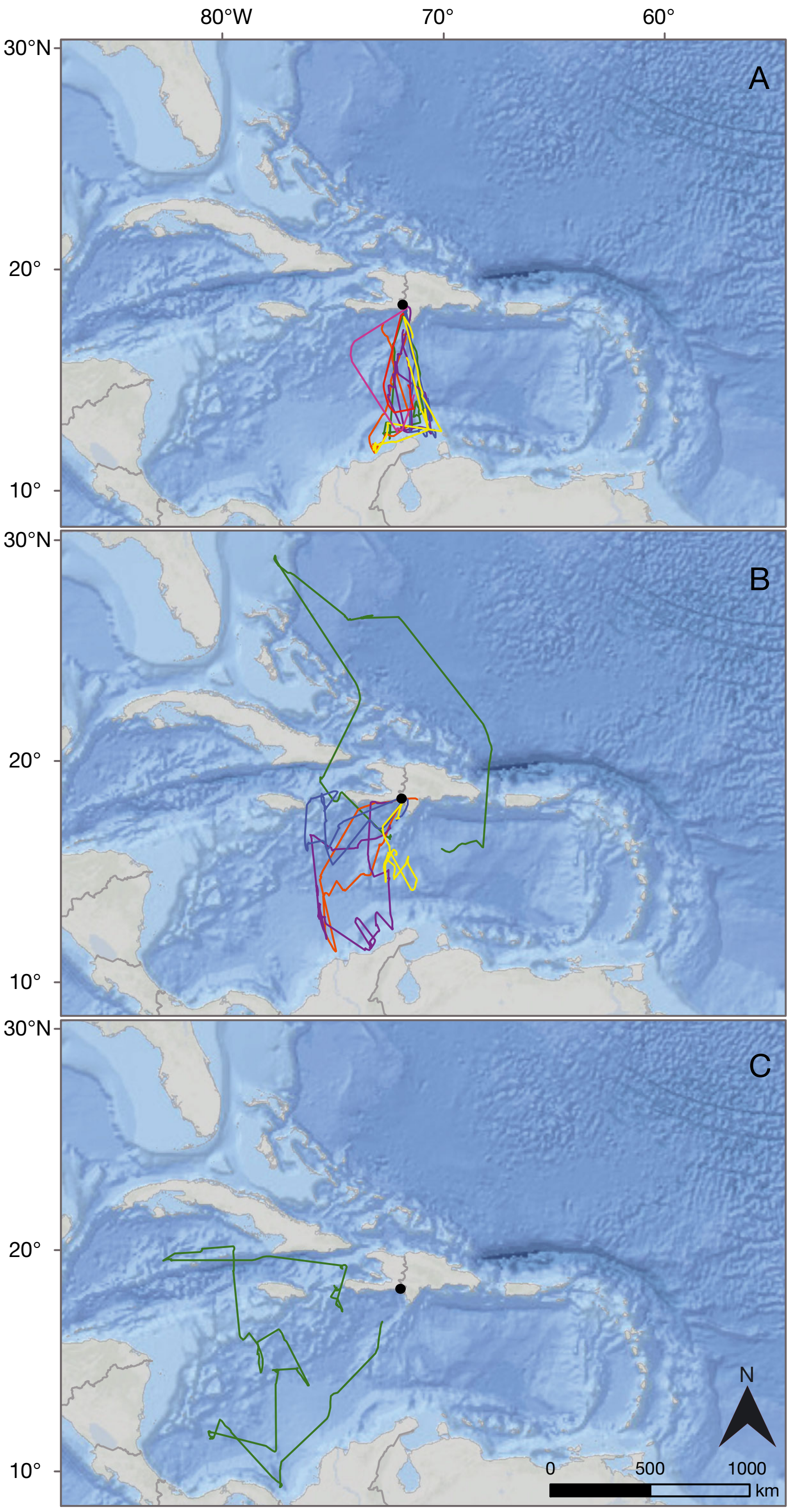

Fig. 2. Movement patterns of satellite-tagged black-capped petrels *Pterodroma hasitata*. (A) Seven trips made by Bird 175 while chick rearing, 8 April to 11 July 2014 (trip no. 1 = green, 2 = orange, 3 = purple, 4 = blue, 5 = yellow, 6 = pink, 7 = red). (B) Five trips by Bird 176 while chick rearing, 10 April to 28 June 2014 (trip no. 1 = green, 2 = orange, 3 = purple, 4 = blue, 5 = yellow). (C) One trip by Bird 177 while possibly chick rearing, 9 April to 13 May 2014. Tracks may not form complete circuits based on timing of location data. Black dots indicate breeding colony

Breeding season

Trail cameras captured 2 complete visits (time-stamped image of bird arriving and departing) from tagged birds (Birds 175 and 176), 5 complete visits from mates of tagged birds (mate of 175, n = 3; mate of 176, n = 2), 7 incomplete visits (time-stamped image of bird arriving or departing but not both) from tagged birds (Birds 175 and 176), and 24 incomplete visits from mates of tagged birds (mates from all 3 pairs, n ≥ 2 visits recorded for each). Arrival times of tagged birds and mates ranged from 22:13 to 04:08 h local time (n = 9), and departure times ranged from 22:04 to 04:17 h local time (n = 36). Time at nest averaged 30.7 ± 8.9 min (pooled among tagged birds and mates, n = 7). Based strictly on images from trail cameras, the mate of Bird 175 was recorded at the nest on 15 occasions (4.8 ± 2.3 d between visits), the mate of Bird 176 on 12 occasions (6.0 ± 3.7 d between visits), and the mate of Bird 177 on 2 occasions (10 and 17 April 2014 but not thereafter).

For Bird 175, we defined 7 trips (Fig. 2A, Table 3; 11.7 ± 3.2 d between visits). During all 7 trips, Bird 175 travelled south across the Caribbean Sea in 1 to 2 d and then spent several days along the northern coast of South America offshore of the Gulf of Venezuela and Guajira Peninsula before returning north across the Caribbean Sea to the nest site in 1 to 2 d. Bird 175 sustained a maximum average speed of 23.3 km h^{-1} during the third trip (no. 175.3) while flying 210 km in 9 h.

For Bird 176, we defined 5 trips (Fig. 2B, Table 3; 14.8 ± 4.2 d between visits). On the first trip away from the nest (no. 176.1), Bird 176 traveled north through the Windward Passage to the continental shelf east of the Gulf Stream. During trip nos. 176.2 through 176.5, Bird 176 remained in the Caribbean Sea and occupied waters west of the Guajira Peninsula, off the eastern tip of Jamaica, and over the Beata Ridge and Beata Plateau. Bird 176 sustained a maximum average speed of 25.0 km h^{-1} during trip no. 176.1 while flying 225 km in 9 h.

Foraging trips were unclear for Bird 177, which was in the Caribbean Sea through mid-May and near the nest site on 11 May

Table 3. Characteristics of trips made by satellite-tagged black-capped petrels *Pterodroma hasitata* during chick rearing at Sierra de Bahoruco National Park, Dominican Republic. Trip start and end dates were estimated based on a combination of location data from satellite tags and images obtained from trail cameras placed at nest entrances

Bird ID. Trip no.	Trip duration (d)	Total distance (km)	Maximum distance (km)	Dates and destinations
175.1	10.8	1773	688	8–19 April; offshore Venezuela, Colombia
175.2	13.3	1694	769	21 April–2 May; offshore Colombia
175.3	12.0	2366	669	3–14 May; offshore Venezuela, Colombia
175.4	12.0	2115	693	15–26 May; offshore Venezuela, Colombia
175.5	18.7	2262	768	27 May–14 June; offshore Venezuela, Colombia, Aruba
175.6	7.9	1378	653	15–22 June; offshore Colombia
175.7	8.0	1137	552	24–30 June; Caribbean Sea (missing data)
176.1	13.7	4172	1487	10–24 April; Caribbean Sea to Windward Passage to northeast of Bahamas to Mona Passage
176.2	10.9	2461	862	25 April–5 May; Caribbean Sea, offshore Colombia
176.3	22.5	3624	825	6–27 May; Caribbean Sea, offshore Colombia
176.4	14.6	2432	561	28 May–11 June; Caribbean Sea
176.5	13.5	1741	475	12–24 June; Caribbean Sea, Aruba Gap

but not thereafter (Fig. 2C, Table 3). On 13 May, Bird 177 departed the Caribbean Sea. During this post-breeding time, Bird 177 sustained a maximum average speed of 21.9 km h^{-1} while flying 153 km in 7 h.

Nonbreeding season

Nonbreeding tracks and use areas were defined to occur after birds no longer returned to nest sites (Fig. 3). Post-breeding dispersal began on 13 May 2014 for Bird 177, on 25 June 2014 for Bird 176, and on 11 July 2014 for Bird 175.

Bird 175 exited the Caribbean Sea through the Windward Passage and then travelled north over the next 3 to 4 d before paralleling the Bahamas in the vicinity of the Antilles Current (Fig. 3A). Until transmissions ceased on 30 August, Bird 175 occupied waters over the continental shelf near the Blake Plateau and Charleston Bump (Fig. 3A,C; 25 July to 10 August) and then east of the shelf near Pamlico Canyon, Hatteras Canyon, and Hatteras Ridge (Fig. 3B; 12 to 28 August). The final days of transmission from 26 to 30 August were from the South Atlantic Bight near the Blake Spur. Maximum longitude reached was 69.8° W, and maximum latitude reached was 35.5° N. During the nonbreeding season, Bird 175 sustained a maximum average speed of 15.3 km h^{-1} while flying 46 km in 3 h.

Bird 176 exited the Caribbean Sea through the Windward Passage before paralleling the Bahamas in the vicinity of the Antilles Current (Fig. 3A). Bird 176 occupied waters east of the shelf (3 July to 10 August; Fig. 3A,B) and east and north of the Blake Spur (11 to 24 August, Fig. 3A,C). Maximum longitude reached was 67.2° W, and maximum latitude reached was 35.5° N. During the nonbreeding season, Bird 176 sustained a maximum average speed of 19.7 km h^{-1} while flying 79 km in 4 h.

Bird 177 exited the Caribbean Sea ca. 13 May through the Windward Passage (Fig. 3A). Bird 177 also approached the South Atlantic Bight via the Antilles Current. Bird 177 remained over the central and eastern shelf in the South Atlantic Bight from ca. 18 May until 6 June. From ca. 7 June to 25 August, Bird 177 was located primarily in pelagic waters east of the shelf and within ca. 250 km of the Blake Spur (Fig. 3C). Bird 177 then crossed back into shelf waters north of Jacksonville Canyon ca. 25 August, approached to within 40 km of the Florida coast, then traveled northeast and occupied waters over the shelf in the South Atlantic Bight until ca. 1 September. From early September through ca. 22 October, Bird 177 occupied waters primarily east of the shelf break between ca. 31.25° and 38° N. Between 31 October and 2 November, Bird 177 traveled ca. 900 km to the southeast, crossing south over Gentry Bank towards Hispaniola and ultimately arriving at or very near the breeding site on 4 November 2014, the final day of signal transmission (Fig. 3A). During the nonbreeding season, Bird 177 sustained a maximum average speed of 23.1 km h^{-1} while flying 207 km in 9 h.

Extent of at-sea range

The Atlantic Seabird Compendium includes ca. 5000 observations of black-capped petrels at sea

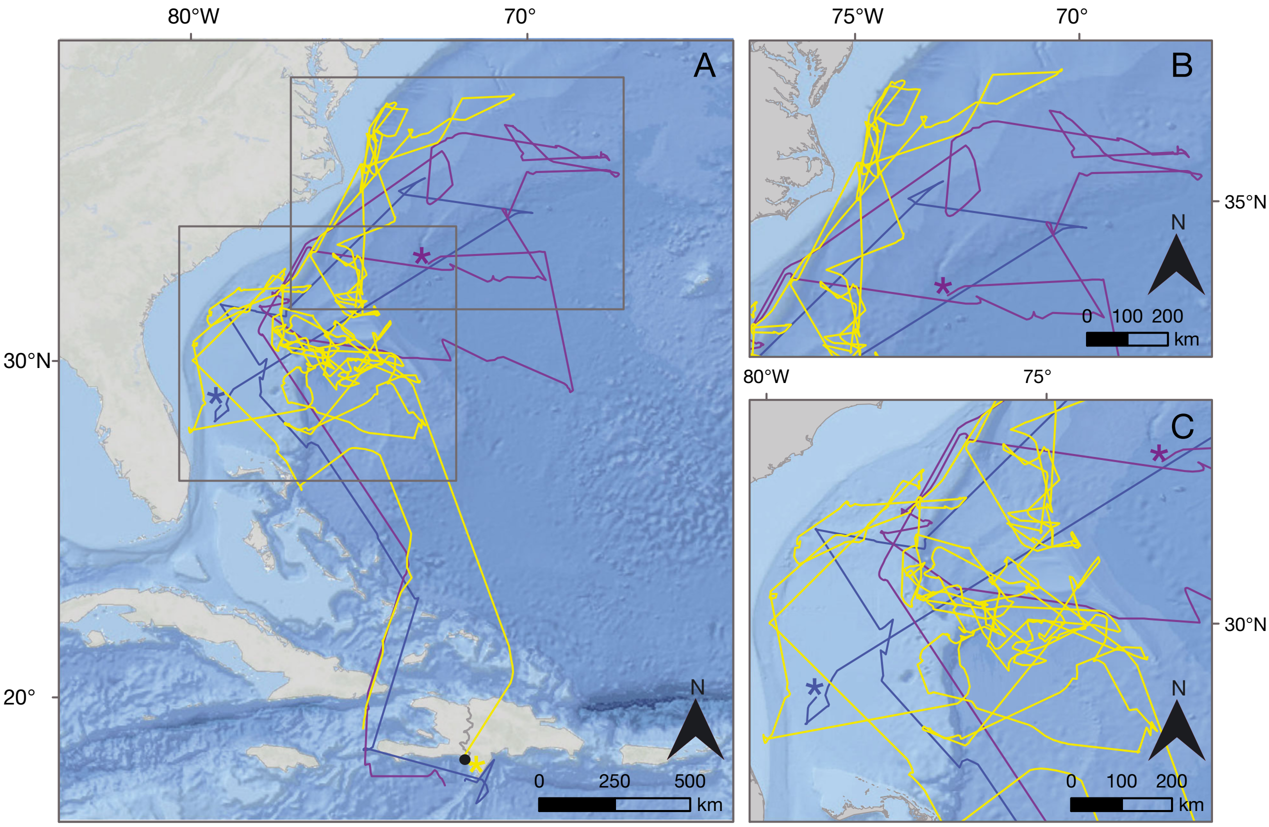

Fig. 3. Movement patterns during the nonbreeding season of satellite-tagged black-capped petrels *Pterodroma hasitata*. (A) Bird 175 (blue), 11 July to 30 August 2014; Bird 176 (purple), 28 June to 25 August; Bird 177 (yellow), 13 May to 4 November 2014. Birds 175 and 176 fledged chicks prior to departure of nesting area. (B) Detail of movements off Cape Hatteras, North Carolina, USA. (C) Detail of movements around the Blake Spur. Black dot indicates breeding colony. Stars show locations of last transmissions

from 1976 to 2006 (O'Connell et al. 2009, Simons et al. 2013). The core of the marine range based on these data is the western edge of the Gulf Stream off Cape Hatteras, centered on ca. 35° N, 75° W, and is ca. 50 km offshore. A second, less dense cluster of observations also occurs within the South Atlantic Bight, between ca. 30° and 33° N, 80° and 78° W, and is 100 to 150 km offshore. Location data derived from satellite tags suggest a similar but more spatially expansive range (Fig. 4), including regular occurrence in the Caribbean Sea between Hispaniola and South America and regular occurrence east of the Gulf Stream and to the north, east, and south of the

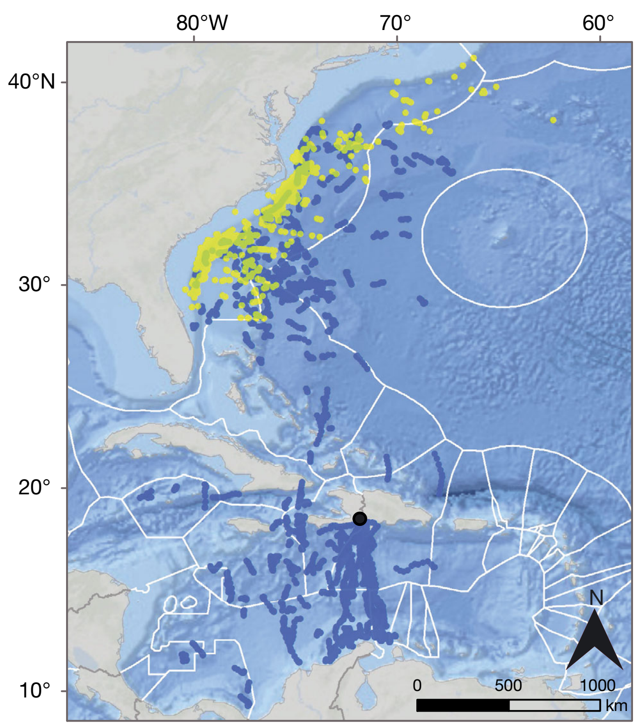

Fig. 4. Overlap of location data from satellite-tagged black-capped petrels *Pterodroma hasitata* (n = 1642 locations, April to November 2014, blue) and observation data archived in the Atlantic Seabird Compendium (O'Connell et al. 2009, yellow). Compendium data are described in detail in Simons et al. (2013). White polygons indicate boundaries of exclusive economic zones (EEZ: VLIZ 2014). Black dot indicates breeding site

Blake Spur. Locations in the Caribbean Sea were derived primarily from Birds 175 and 176 during trips between nest visits, while locations in and east of the Gulf Stream were derived during the post-breeding season from all 3 birds.

Satellite-tagged petrels occurred, were located within the Exclusive Economic Zone (EEZ) (VLIZ 2014) of 14 different countries plus international waters. The highest number of locations (22 %) occurred, and days (21 %) were spent, in international waters. This was followed by waters designated as US (19 % of both locations and days), Colombian (12.5 % of both locations and days), and Bahaman (12 % of both locations and days; Table 4). Use of Panamanian and Venezuelan waters adds 2 new countries to the range for the species.

DISCUSSION

Marine locations: breeding and nonbreeding seasons

Our results are the first to document individual movements of black-capped petrels, among the first to describe individual movement patterns for seabirds in the Caribbean, and one of only a few studies to track *Pterodroma* species. Two of the 3 tagged birds fledged a chick, while the third failed due to burrow collapse, indicating that tagged birds did not abandon chicks. During the breeding season, satellite-tagged black-capped petrels frequented waters of the Caribbean Sea south and southwest of the breeding site on Hispaniola. Because petrels are commonly observed along the western edge of the Gulf Stream and over the continental shelf offshore of the USA during spring and summer months, it has often been suspected that breeding birds commute there from nest sites (Haney 1987, Simons et al. 2013). Only 1 of the 3 birds we tracked commuted to this region while rearing a chick, although we have no tracking data during incubation and our sample size was small.

Table 4. Use of exclusive economic zones (EEZs, as defined by VLIZ 2014) by satellite-tagged black-capped petrels *Pterodroma hasitata*, April to November 2014

EEZ	No. of days with ≥1 location	No. of locations
Aruba	2	13
Bahamas	42	275
Colombia	49	412
Cuba	5	33
Caymans	6	33
Dominican Republic	40	337
Haiti	31	193
Jamaica	21	143
Nicaragua	4	28
Panama	5	25
Puerto Rico	1	3
Turks and Caicos	1	5
USA	102	725
Venezuela	23	141
International waters	77	566

Both of the birds that fledged chicks made repeated foraging trips within the Caribbean Sea during chick rearing. Eleven of 12 trips recorded from Birds 175 and 176 occurred in waters offshore of the Gulf of Venezuela, the Guajira Peninsula, and the embayment southwest of the Guajira Peninsula. High fidelity to foraging sites in seabirds occurs when prey availability is predictable (Weimerskirch 2007). Habitat features such as shelf breaks or eddies may promote such consistency, although the temporal and spatial scale at which mechanisms operate may vary. For example, black-browed albatrosses *Thalassarche melanophrys* from the Kerguelen Islands consistently forage at the same sites over shelf breaks during the breeding season, but the same species, when breeding at Campbell Island and foraging at frontal zones which can vary in location and strength, demonstrates less fidelity to feeding sites among trips (Weimerskirch et al. 1997, Croxall et al. 1997, Weimerskirch 2007). In our study area, oceanographic data suggest that primary productivity may be relatively high within a narrow band of water offshore of the coasts of Venezuela and Colombia, at least during spring and summer months (NASA Aqua MODIS, accessed on 10 April 2015 via BloomWatch 360 at www.coastwatch.pfel.noaa.gov). Further, Andrade & Barton (2005) describe a consistent upwelling feature off the Guajira Peninsula which can extend ca. 250 km offshore to the northwest, which can be present but variable in strength year-round, and which appears to concentrate forage fish (Paramo et al. 2003). Upwelling zones, shelf breaks, and areas of high primary productivity serve as high-quality habitats for foraging seabirds in other oceanic regions, although comparative data within the gadfly petrels are sparse (Phillips et al. 2006, Rodriguez et al. 2013).

Trip length for tagged black-capped petrels appeared to be relatively high compared to other species in the order Procellariiformes and similar to other species in the genus *Pterodroma*. Adams & Flora (2010) report a 19 d trip for a breeding (undefined as incubating or chick rearing) Hawaiian petrel *Pterodroma sanwichensis*. Simons (1985) found that feeding intervals in Hawaiian petrels increased as chick age increased and that during the 30 d prior to fledging, chicks were fed on average once every 10 d. Pollet et al. (2014b) report maximum foraging ranges, during incubation periods, for 25 species of Procellariiformes (range from ca. 250 km in diving petrels to ca. 3800 km in great shearwaters *Puffinus gravis*) and a range:mass index (range from 0.12 in black-browed albatrosses to 24.13 in Leach's storm-petrels *Oceanodroma leucorhoa*). During our study, foraging trip length of tagged birds during chick rearing averaged 2200 km, and the range:mass ratio averaged 5.5. Our average range:mass ratio is within the range reported for 3 other gadfly petrels (Chatham petrel *Pterodroma axillaris* = 10.47, Barau's petrel *Pterodroma baraui* = 6.23, grey-faced petrel *Pterodroma macroptera* = 3.86), although data may not be directly comparable due to potential differences in foraging behavior between incubation (Pollet et al. 2014b) and chick rearing (our study). For example, foraging ranges of many procellariiform species tend to be smaller during chick rearing compared to incubation phases (Rayner et al. 2012), and differences in characteristics of foraging trips may also occur between sexes. Thus, our small sample may not include an accurate description of the variability that likely occurs in the characteristics of foraging trips for the black-capped petrel.

Time at nest during provisioning was brief (<45 min). All arrivals and departures occurred between 22:00 and 04:00 h local time. Comparative data from other *Pterodroma* species are sparse, although nest visits for blue petrels *Halobaena caerulea* were also brief (<65 min) and occurred during the night (Chaurand & Weimerskirch 1994). Trip duration during our study ranged from 8 to 22 d for tagged birds but, based solely on images captured on trail cameras, appeared to be shorter for mates of tagged birds. Tagged birds may therefore be experiencing a potential tag effect, although fledging success did not appear to be affected. Villard et al. (2011) found that Cory's shearwaters equipped with satellite tags provisioned lighter meals to chicks but that fledging success was not affected. Continued miniaturization in transmitter design has decreased the mass of solar-powered satellite tags to ca. 5 g (compared to the 9.5 g tags we used) and could allow for future tag packages to weigh <2% of body mass in this species.

Haney (1987) suggested that black-capped petrels were likely to migrate to wintering areas in the South Atlantic Bight along the Antilles Current north and east of the Bahamas. Our tracking data confirm that path. All 3 tagged birds exited the Caribbean Sea via the Windward Passage and then travelled north and west in the range of the Antilles Current. The shelf waters west of the Gulf Stream offshore of Cape Hatteras, North Carolina, and within the South Atlantic Bight supported most of the nonbreeding locations for petrels in our study, and both of these areas also support most of the existing observations of petrels (Haney 1987, O'Connell et al. 2009, Simons et al. 2013). Tagged petrels, however, also occurred east of the Gulf Stream more frequently than documented by previous reports (Haney 1987, O'Connell et al. 2009, Simons et al. 2013). During our study, petrel use was common near the Blake Spur, an area on the eastern edge of the Gulf Stream that has received little attention in terms of seabird or oceanographic surveys but that appears to support strong currents and high densities of benthic fauna (Genin et al. 1992). Larval fish may also be concentrated in regions such as the Blake Spur where currents are strong or where they mesh, or where eddies or rings form (Knights 2003).

Comparable and published tracking data are sparse for gadfly petrels in the western North Atlantic. Originating from breeding sites along the coast of Portugal, the nonbreeding distribution of the Bugio petrel *Pterodroma deserta* (commonly known as Desertas petrel) includes the Gulf Stream and South Atlantic Bight (Ramirez et al. 2013). Bugio petrels may use these areas due to lower sea surface temperatures and higher chl *a* concentrations (an indication of higher primary productivity). Madeiros (2012) also documented use of waters east of the Gulf Stream by cahow during their breeding season but did not address potential underlying mechanisms.

Data quality and tagging

Tag retention during our study (136 to 208 d) was sufficient to allow us to track birds through chick rearing and into the nonbreeding season, and in one case to track a bird back to the breeding site at the start of the subsequent breeding season. The same attachment method has resulted in shorter average tracking durations with grey-faced petrels *Pterodroma macroptera gouldi* (mean ± SE = 51 ± 5 d, n = 32; MacLeod et al. 2008), although these tags weighed ~5% of the birds' body mass and had an expected battery life of only 60 d. Other species tracked with battery-powered platform transmitter terminals attached using the same methods we used showed tracking durations similar to ours (spectacled petrels *Procellaria conspicillata* [mean ± SD = 130 ± 53 d, n = 8; Reid et al. 2014], shearwaters *Puffinus* spp. [mean ± SD = 162 ± 78, n = 50; R. A. Ronconi unpubl. data]). Ultimately, the fates of 2 of our 3 tagged birds (Birds 175 and 176) remain unknown. Sutures may have failed, tags may have detached for some other reason, or birds may have perished prior to the initiation of the 2015 breeding season. We did document, however, that the burrows from which Birds 175 and 176 were captured were occupied at the start of the 2015 breeding season. While not confirmatory, this observation does suggest those 2 birds may have returned to breed given the low breeding and burrow density for this species and the relatively high fidelity to nest sites observed in petrels and shearwaters, particularly when pairs breed successfully (Warham 1990).

Approximately 90% of all locations were estimated from 4 satellite messages and hence included an accuracy estimate, suggesting that satellite tags at lower latitudes in this region were not prone to poor accuracy levels. Approximately 71% of locations, however, were estimated with an accuracy >500 m, which is adequate for mapping migratory routes, determining ranges during breeding and nonbreeding, and even determining presence at a breeding site. More careful consideration needs to be given, however, if data from satellite tags are to be used to relate bird locations to local conservation threats. For example, if the accuracy of the location estimate was >500 m then we could determine if a bird was in the vicinity of a potential threat such as a pollution source (i.e. macroscale exposure, Burger et al. 2011). This level of accuracy would not, however, readily permit us to determine whether a bird was so close to a potential threat that an interaction would likely occur (i.e., meso- or microscale exposure, Burger et al. 2011). GPS-level accuracy would allow for such assessments, and such technology is becoming increasingly available on lighter-weight tags. The temporal resolution of the data also needs to be considered for conservation purposes. Smaller satellite tags often collect data less frequently, in our case for 8 of every 32 h. Seabirds, particularly petrels, can cover a substantial distance during these nontransmission periods. For example, birds in our study were located 300 to 600 km from previous locations after a 24 h nontransmission period. Therefore, a substantial gap in locations can occur, which may affect the reliability of threat assessment or habitat use for conservation planning. Increased sample sizes may help offset these concerns.

Use of EEZs

Seabirds regularly cross political boundaries, and tracking data provide an effective tool to detail such movements and therefore provide an ecological link among countries (Gonzalez-Solis et al. 2007, Jodice & Suryan 2010, Pollet et al. 2014a). For example, Suryan et al. (2007) documented the use of 6 EEZs by short-tailed albatrosses *Phoebastria albatrus* along the rim of the north Pacific and assessed by-catch risk in each. The Caribbean Sea, Gulf of Mexico, and waters adjacent to the southern Gulf Stream, as well as international waters, contain ca. 25 EEZs. Birds in our study occupied 56% of the EEZs available in this broad area during a period of 4 to 6 mo. Therefore, although conservation actions targeted at breeding sites of black-capped petrels can focus on a limited number of nations, those targeted at marine use areas must consider a large number of countries with a diverse array of laws, policies, environmental attributes, and resource use. For example, areas in the South Atlantic Bight that appear to support petrels are under consideration for development of oil and gas leasing (Goetz et al. 2012, Bureau of Ocean Energy Management 2015), while concern exists about potential risks to petrels from development of offshore wind facilities in the Caribbean (Goetz et al. 2012). Furthermore, while the species is afforded some legal protection in each country in which it is known to or suspected to breed, protection in nations where the species does not breed but where it uses marine habitats is far more difficult to assess (Goetz et al. 2012). Some international plans such as The Protocol Concerning Specially Protected Areas and Wildlife, however, may afford some protection in countries where the species uses marine habitats. As additional movement data are collected for the species and as a more complete picture of EEZ use throughout the entire annual cycle becomes available, a more thorough investigation of legal protection and policies can be undertaken.

In summary, our results document movement patterns and use areas of individual black-capped petrels during both breeding and nonbreeding phases. Prior to our tracking efforts, the marine range of the black-capped petrel was based solely on at-sea observations from surveys and opportunistic sightings (Haney 1987, O'Connell et al. 2009, Simons et al. 2013). During the breeding season, we observed regular use of the Caribbean Sea during chick rearing, while post-breeding birds used waters of the South Atlantic Bight, offshore of Cape Hatteras, and waters east of the Gulf Stream. Although not a species that breeds in the USA, our data suggest that the species spends as much time in US waters as in any other individual country. Our research demonstrated the feasibility of tracking this endangered species, but our limited sample size prohibits detailed habitat modeling or risk assessment. Additional tracking studies conducted throughout the annual cycle would benefit such efforts and better inform conservation plans for the species.

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LITERATURE CITED

Adams J, Flora S (2010) Correlating seabird movements with ocean winds: linking satellite telemetry with ocean scatterometry. Mar Biol 157:915–929

Andrade CA, Barton ED (2005) The Guajira upwelling system. Cont Shelf Res 25:1003–1022

BirdLife International (2015) IUCN Red List for birds. www.birdlife.org (accessed 20 March 2015)

Bureau of Ocean Energy Management (2015) 2017–2022 outer continental shelf oil and gas leasing draft proposed program. US Dept of the Interior, Bureau of Ocean Energy Management, Washington, DC. www.boem.gov/2017-2022-DPP/ (accessed 20 March 2015)

Burger J, Gordon C, Lawrence J, Newman J, Forcey G, Vlietstra L (2011) Risk evaluation for federally listed (roseate tern, piping plover) or candidate (red knot) bird species in offshore waters: a first step for managing the potential impacts of wind facility development on the Atlantic outer continental shelf. Renew Energy 36: 338–351

Chaurand T, Weimerskirch H (1994) The regular alternation of short and long foraging trips in the blue petrel *Halobaena caerulea*: a previously undescribed strategy of food provisioning in a pelagic seabird. J Anim Ecol 63: 275–282

Croxall JP, Prince PA, Rothery P, Wood AG (1997) Population changes in albatrosses at South Georgia. In: Robertson G, Gales R (eds) Albatross biology and conservation. Surrey Beatty & Sons, Chipping Norton, p 69–83

Douglas L (2000) The Jamaica petrel in the Caribbean. In: Schreiber EA, Lee DS (eds) Status and conservation of West Indian seabirds. Spec Publ Soc Carib Ornithol 1: 19–24

Genin A, Paul CK, Dillon WP (1992) Anomalous abundances of deep-sea fauna on a rocky bottom exposed to strong currents. Deep Sea Res Part A 39:293–302

Goetz JE, Norris JH, Wheeler JA (2012) Conservation action plan for the black-capped petrel (*Pterodroma hasitata*). International Black-capped Petrel Conservation Group. www.fws.gov/birds/waterbirds/petrel (accessed on 13 Oct 2015)

Gonzalez-Solis J, Croxall JP, Oro D, Ruiz X (2007) Trans-equatorial migration and mixing in the wintering areas of a pelagic seabird. Front Ecol Environ 5:297–301

Haney JC (1987) Aspects of the pelagic ecology and behavior of the black-capped petrel (*Pterodroma hasitata*). Wilson Bull 99:153–168

Jodice PGR, Suryan RM (2010) The transboundary nature of seabird ecology. In: Trombulak SC, Baldwin RF (eds) Landscape-scale conservation planning. Springer, Dordrecht, p 139–165

Jodice PGR, Tavano J, Mackin W (2013) Chapter 8: marine and coastal birds and bats. In: Michel J (ed) South Atlantic information resources: data search and literature synthesis. US Dept of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2013-01157, p 475–587

Jonsen ID, Basson M, Bestley S, Bravington MV and others (2013) State-space models for bio-loggers: a methodological road map. Deep-Sea Res II 88-89:34–46

Knights B (2003) A review of the possible impacts of long-term oceanic and climate changes and fishing mortality on recruitment of anguillid eels of the Northern Hemisphere. Sci Total Environ 310:237–244

Le Corre M, Ollivier A, Ribes S, Jouventin P (2002) Light-induced mortality of petrels: a 4-year study from Réunion Island (Indian Ocean). Biol Conserv 105:93–102

MacLeod CJ, Adams J, Lyver P (2008) At-sea distribution of satellite-tracked grey-faced petrels *Pterodroma macroptera gouldi* captured on the Ruamaahua (Aldermen) Islands, New Zealand. Pap Proc R Soc Tasman 142:73–88

Madeiros J (2012) Cahow recovery program 2011–2012 breeding season report. Department of Conservation Services, Ministry of Public Works, Bermuda

O'Connell AF, Gardner B, Gilbert AT, Laurent K (2009) Compendium of avian occurrence information for the continental shelf waters along the Atlantic coast of the

United States: final report (database section — seabirds). USGS Patuxent Wildlife Research Center, Beltsville, MD. Bureau of Ocean Energy Management Headquarters, OCS Study BOEM 2012-076

Paramo J, Quinones RA, Ramirez A, Wiff R (2003) Relationship between abundance of small pelagic fishes and environmental factors in the Colombian Caribbean Sea: analysis based on hydroacoustic information. Aquat Living Resour 16:239–245

Phillips RA, Silk JRD, Croxall JP, Afanasyev V (2006) Year-round distribution of white-chinned petrels from South Georgia: relationships with oceanography and fisheries. Biol Conserv 129:336–347

Pollet IL, Hedd A, Taylor PD, Montevecchi WA, Shutler D (2014a) Migratory movements and wintering areas of Leach's storm-petrels tracked using geolocators. J Field Ornithol 85:321–328

Pollet IL, Ronconi RA, Jonsen ID, Leonard ML, Taylor PD, Shutler D (2014b) Foraging movements of Leach's storm-petrels *Oceanodroma leucorhoa* during incubation. J Avian Biol 45:305–314

Ramirez I, Paiva VH, Menezes D, Silva I, Phillips RA, Ramos JA, Garthe S (2013) Year-round distribution and habitat preferences of the Bugio petrel. Mar Ecol Prog Ser 476: 269–284

Rayner MJ, Taylor GA, Gummer HD, Phillips RA, Sagar PM, Shaffer SA, Thompson DR (2012) The breeding cycle, year-round distribution and activity patterns of the endangered Chatham petrel (*Pterodroma axillaris*). Emu 112:107–116

Reid TA, Ronconi RA, Cuthbert RJ, Ryan PG (2014) The summer foraging ranges of adult spectacled petrels *Procellaria conspicillata.* Antarct Sci 26:23–32

Rodriguez B, Becares J, Martinez JM, Rodriguez A, Ruiz A, Arcos JM (2013) Satellite tracking of Bulwer's petrels *Bulweria bulwerii* in the Canary Islands. Bird Study 60: 270–274

Ronconi RA, Ryan PG, Ropert-Coudet Y (2010) Diving of great shearwaters (*Puffinus gravis*) in cold and warm water regions of the South Atlantic Ocean. PLoS ONE 5: e15508

Simons TR (1985) Biology and behavior of the endangered Hawaiian dark-rumped petrel. Condor 87:229–245

Simons TR, Lee DS, Haney JC (2013) Diablotin (*Pterodroma hasitata*): a biography of the endangered black-capped petrel. Mar Ornithol 41:S3–S43

Suryan RM, Dietrich KS, Melvin EF, Balogh GR, Sato F, Ozaki K (2007) Migratory routes of short-tailed albatrosses: use of exclusive economic zones of North Pacific Rim countries and spatial overlap with commercial fisheries in Alaska. Biol Conserv 137:450–460

Villard P, Bonenfant C, Bretagnolle V (2011) Effects of satellite transmitters fitted to breeding Cory's shearwaters. J Wildl Manag 75:709–714

VLIZ (Flanders Marine Institute) (2014) Maritime boundaries geodatabase, version 8. www.marineregions.org/ (accessed 19 March 2015)

Warham J (1990) The petrels: their ecology and breeding systems. Academic Press, London

Weimerskirch H (2007) Are seabirds foraging for unpredictable resources? Deep-Sea Res II 54:211–223

Weimerskirch H, Mougey T, Hindermeyer X (1997) Foraging and provisioning strategies of black-browed albatrosses in relation to the requirements of the chick: natural variation and experimental study. Behav Ecol 8: 635–643

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