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Authors: Cecere, Jacopo G., Calabrese, Licia, Rocamora, Gerard, and Catoni, Carlo

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Movement Patterns and Habitat Selection of Wedge-tailed Shearwaters (*Puffinus pacificus*) Breeding at Aride Island, Seychelles

Jacopo G. Cecere[1,2,*], Licia Calabrese[3,4], Gerard Rocamora[3] and Carlo Catoni[5]

[1]ISPRA - Institute for Environmental Protection and Research, Via Cà Fornacetta 9, 40064, Ozzano dell'Emilia, Italy

[2]RicercaFauna, Via Caio Canuleio 83, 00174, Roma, Italy

[3]Island Conservation Society, BP 775, Pointe Larue, Mahé, Seychelles

[4]Centre d'Etudes Biologiques de Chizé, Centre Nationale Recherche Scientifique, 79360, Villiers en Bois, France

[5]Ornis italica, Piazza Crati 15, 00199, Roma, Italy

[*]Corresponding author; E-mail: jacopo.cecere@isprambiente.it

Abstract.—Seabird movements during foraging trips and their preference for particular areas have recently been the focus of many studies aimed at gaining a better understanding of the ecological requirements of several species. During the last decade, the use of new devices, such as Global Positioning System (GPS) devices and geo-locator loggers, has allowed researchers to perform more investigations of this type. GPS devices were used on Wedge-tailed Shearwaters (*Puffinus pacificus*) breeding on Aride Island, Seychelles, to identify the main foraging areas used during early chick-rearing and to assess at-sea foraging habitat selection. Thirteen foraging trips were recorded, 61.5% of which lasted 1 day. One main foraging area, located approximately 100 km east of the colony just outside a granitic bank characterized by upwelling and higher values of primary production compared to surrounding areas, was identified. The foraging area size (3,313 km^2) was much smaller than that identified during late chick-rearing (160,000 km^2) in a previous study. This is probably due to the exigency to feed chicks more regularly and hence to find foraging areas closer to the colony during the early chick-rearing. The identification of key marine conservation areas, like those identified in this study, is a priority for designating marine Important Bird Areas and identifying habitat management measures. The results of this study should be relevant for the development of conservation plans for Wedge-tailed Shearwaters and for other seabirds in the area. *Received 11 May 2013, accepted 8 July 2013.*

Key words.—foraging, foraging area, geo-locator loggers, Global Positioning System, habitat selection, *Puffinus pacificus*, Wedge-tailed Shearwaters.

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During the last decade, the use of Global Positioning System (GPS) devices and remote sensing technology has provided scientists with a large amount of information about bird movements, even over the open sea (Wakefield *et al.* 2009). Furthermore, the ability to link accurate bird positions to remote sensing data has facilitated the analysis of habitat selection and use by pelagic bird species (Wakefield *et al.* 2009). This kind of information is particularly relevant for conservation purposes, and GPS telemetry has been included in the standard methodology adopted to identify marine Important Bird Areas around the globe (BirdLife International 2010).

While several studies have been published about the habitat use of different seabird species (Wakefield *et al.* 2009), to our knowledge, nobody has yet deployed this technology to both analyze movement patterns and determine habitat selection of Wedge-tailed Shearwaters (*Puffinus pacificus*). Wedge-tailed Shearwaters are a medium-sized tubenose species that ranges across the tropical Pacific and Indian Oceans where threats to the populations include unsustainable levels of fish exploitation, persecution, predation by invasive species and the over-exploitation of tuna fisheries (Brooke 2004). Catry *et al.* (2009) were the first to document the movements of Wedge-tailed Shearwaters using geo-locator loggers (GLS) during late chick-rearing, non-breeding and pre-breeding periods. This study focuses on the same population, breeding at Aride Island Nature Reserve, Seychelles, but during early chick-rearing, a critical period during which the chicks of shearwater species generally need to be fed often (Klomp and Furness 1992), thus forcing adults to find prey near the colony (Cecere *et al.* 2013). In addition, instead of GLS, we used GPS technology which allowed us to determine bird position with a much greater accuracy and resolution.

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The objectives of this study were to: 1) identify the main foraging areas exploited by Wedge-tailed Shearwaters breeding at Aride Island during the early chick rearing period and compare these areas with those used during the late chick-rearing period as assessed by Catry *et al.* (2009); and 2) investigate whether birds from Aride Island select upwelling areas characterized by high values of primary production. Such environmental features are normally associated with the presence of large fish schools (Blanchette *et al.* 2009).

Methods

Study Area

The study was carried out on Aride Island (4° 12' 46" S, 55° 39' 53" E), the northernmost granitic island in the Seychelles. Aride Island occurs within the Seychelles bank, which forms the northern part of the Mascarene plateau, an arc aseismic ridge extending south 2,000 km from the Seychelles to La Réunion and west through the Amirantes between the Somali and Mascarene Basins. The Seychelles bank is mostly shallower than 125 m and is characterized by an enhanced oceanic productivity caused by interaction of the banks with the South and North Equatorial Currents (Tomczak and Godfrey 2003). This interaction is likely important for ocean food webs as indicated by seabirds and whales using the Seychelles Basin (Obura *et al.* 2012).

The island is a nature reserve of approximately 73 ha, where the only human inhabitants are the reserve's staff and volunteers. The island hosts over one million seabirds belonging to 10 species (Skerrett and Disley 2011). The colony of Wedge-tailed Shearwaters consists of an estimated 18,500 pairs (Rocamora and Skerrett 2001). The Wedge-tailed Shearwaters of the Aride Island colony bred rather asynchronously with both eggs and 1-15 day-old chicks in the nests during mid-October and early November 2012 when the study was carried out (J. G. Cecere, pers. obs.). The colony is mainly located along the southern part of the island. Sampled nests were located throughout the colony (Range = 2-553 m distance between sampled nests). Only nests with young chicks with down and no growing feathers on the tail and wings were used for the study.

GPS Logger Deployment

Wedge-tailed Shearwaters breed in burrows, making it very easy to catch the adults by hand during the night just after they have fed their chicks. Wedge-tailed Shearwaters were banded and weighed and a mini-GPS logger (see below) was attached to the back feathers using 3-4 strips of Tesa marine cloth tape (Wilson *et al.* 1997). Total handling time was kept below 10 min, and individuals were returned to their nests immediately afterward. Nesting burrows are usually not deep, allowing researchers to see, keep and weigh the chick while an adult was tagged.

Nests were monitored every night from dusk to dawn, checking each target nest four or five times per night. Once a bird with a GPS device returned to the nest, it was recaptured and the GPS logger removed by peeling away the tape from the feathers. Mini-GPS loggers with strip antennas (Technosmart Europe) were used. The GPS loggers carried two different batteries, one 160 mA and one 250 mA, so the final weight of the devices (waterproof covering and Tesa tape included) was 11 and 12.6 g, respectively. The deployment of the lighter GPS loggers allowed for tracking of lighter birds, despite the shorter life-span of these devices. Device weight (band excluded) averaged 3.45% of the bird's weight (Range = 3.1-3.7%), so that Wedge-tailed Shearwaters should not have been influenced by the extra-mass (Passos *et al.* 2010). All GPS loggers were configured to record at the same time both the position and the instantaneous speed of the marked individual every 10 min. A foraging trip began with a departure from the nest and ended at the first return to the nest.

Analyses

The main areas used by tracked birds were identified by means of kernel analyses using only GPS positions with an instantaneous speed of less than 9 kph. This threshold has been used to identify positions where Manx (*P. puffinus*) and Scopoli's (*Calonectris diomedea*) shearwaters (Guilford *et al.* 2008; Cecere *et al.* 2012) were using the environment for either resting, searching for food, or diving, thus excluding positions where the birds were travelling. Fixed kernels were computed at the probability level of 50%, identifying the core areas used by breeders during foraging trips.

One hundred random points were generated within identified core foraging areas that were considered representative of the habitat used. These 100 random points were compared to 500 random points considered representative of available sea habitat to investigate whether breeding Wedge-tailed Shearwaters selected particular environmental characteristics during foraging trips. These 500 random locations were generated within a buffer zone created around the colony of Aride Island with a radius of 206 km. This radius was determined using the farthest recorded position of tracked birds from the breeding colony (186 km), enlarged with a 20-km buffer (the likely olfactory detection distance for pelagic birds; Nevitt 2008). Random points for both used and available areas were randomly generated using ArcGIS (Environmental Systems Research Institute 2008).

Three variables were selected to characterize both used and available random point locations: 1) sea depth, obtained from the General Bathymetric Chart of the Oceans (GEBCO 08) of the British Oceanographic Data Centre as a 30 arc-second grid (approximately 1 km); 2) minimum distance to the edge of granitic bank; and 3) net primary production data (standard Vertically Generalized Production Model (VGPM)), from the

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Ocean Productivity website. These data have a spatial resolution of 10 arc-min (approximately 18 km) and include sea surface temperature, chlorophyll and photosynthetically active radiation values (Behrenfeld and Falkowski 1997). For each location, we extracted the primary production value of the month in which tracking was performed.

All spatial analyses were performed using ArcGIS (Environmental Systems Research Institute 2008) with the help of different tools: the kernel analysis was performed with the Home Range Tool (Rodgers *et al.* 2007); net primary production raster was converted using Marine Geospatial Ecology Tools (Roberts *et al.* 2010); the extraction of raster values for each point was obtained using the Spatial Analyst Tools package; while all distances were calculated using the ET Geo Wizards package (Tchoukanski 2012). Since all environmental variables were strongly correlated, we chose to use only one of them in the following analysis to avoid problems in parameter estimation (Zuur *et al.* 2007). Hence, habitat selection was assessed using logistic regression with the use/availability of each location being treated as the dependent variable and net primary production being treated as the independent variable (R Development Core Team 2012). The relationship between the maximum distance covered by breeders during their foraging excursion and the weight of the chick at the moment of adult departure was analyzed by linear regression (R Development Core Team 2012).

RESULTS

A total of 14 Wedge-tailed Shearwaters were tagged, but unfortunately four individuals lost their GPS logger. Two consecutive trips were recorded for one bird and three consecutive trips for a second bird. The remaining eight individuals were recorded during only one foraging trip (Table 1). Eleven foraging trips out of 13 were complete, with recorded positions from the beginning to the end. The remaining two trips were incomplete since the device switched off before the first return (after 3 and 4 days), and the birds were re-caught after 8 and 9 days respectively from GPS deployment. In these two cases, we could not determine the temporal length of the trip since we could not conclusively determine if the bird came back to the colony before it was re-caught. Most (61.5%) of the trips lasted 1 day, 15.4% lasted 2 days and the remaining 23.1% lasted > 3 days (Table 1). All birds took the same main direction from the colony, heading east (Fig. 1). Kernel utilization distribution at 50% identified one core area of 3,313 km^2, whose centroid was located about 117 km east of the breeding colony. The exploited area was located just outside the granitic bank, close to its boundaries (Fig. 1). Compared to marine habitat available, breeding Wedge-tailed Shearwaters selected a foraging area characterized by higher values of primary production ($Z = 6.203$, $P < 0.001$). The use range was 323.5-505.2 mg C m^{-2} day^{-1} (average = 404.43 ± 53.5 mg C m^{-2} day^{-1}) while the available range was 267.1-538.7 mg C m^{-2} day^{-1} (average = 356.5 ± 67.1 mg C m^{-2} day^{-1}).

Table 1. Summary data for 10 tracked Wedge-tailed Shearwaters. Parameters are: Device (%) = proportion of device (including waterproof covering and Tesa tape) to each marked individual's weight; Trip Number = number of recorded consecutive trips; % Tracked Days = proportion of tracked days of the total number of days the marked individual spent with the device; and Max Distance (km) = Euclidean distance from the breeding colony and farthest recorded location.

Band Number	Weight (g)	Device (%)	Trip Number	Trip Duration (Days)	% Tracked Days	Trip Start	Max Distance (km)
FS34545	357.8	3.5	1	1	100	24/10/12	87.89
FS34548	360.1	3.5	1	2	100	25/10/12	157.97
			2	1	100	27/10/12	139.43
			3	1	100	28/10/12	137.24
FS34549	366.8	3.4	1	> 4	44	26/10/12	185.73
FS34552	294	3.7	1	1	100	26/10/12	85.69
FS34554	370.8	3.4	1	1	100	27/10/12	119.99
FS34555	383.7	3.3	1	> 3	38	27/10/12	176.93
FS34558	364.6	3.5	1	1	100	29/10/12	133.25
FS34560	342.9	3.7	1	1	100	28/10/12	101.36
			2	2	100	29/10/12	118.19
FS34561	406.8	3.1	1	1	100	30/10/12	147.01
FS34562	368.7	3.4	1	4	100	29/10/12	123.23

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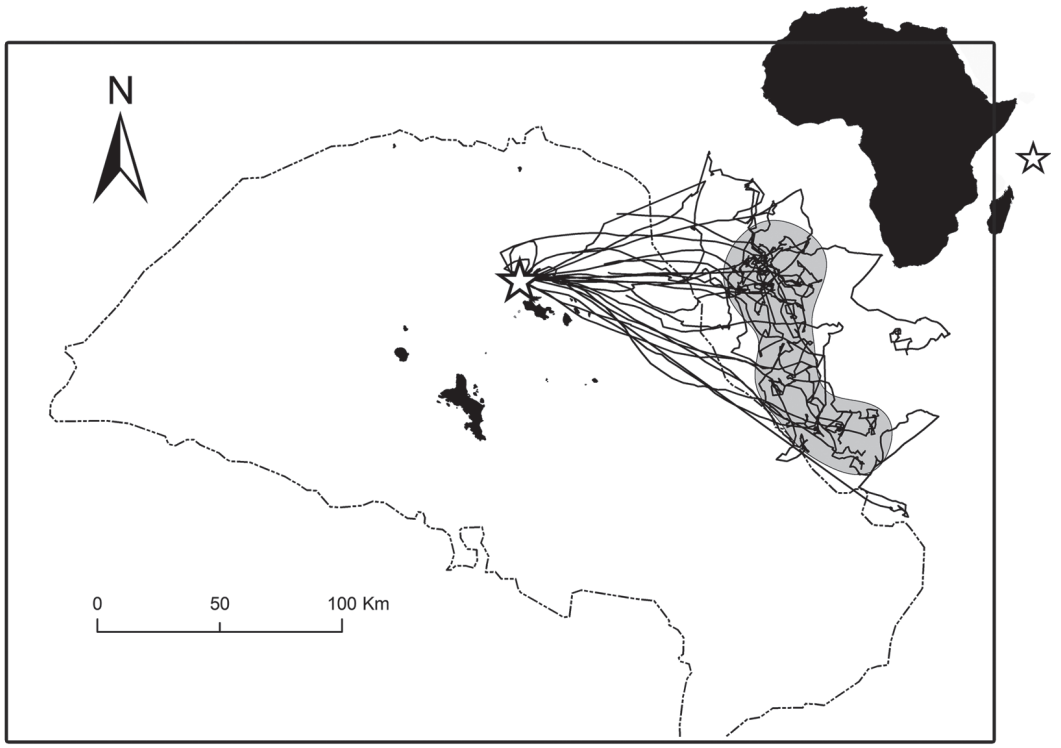


Figure 1. Location of Aride Island, Seychelles (star in center) and tracks of foraging excursions of 10 breeding birds recorded during chick-rearing (13 foraging trips). The core area (fixed kernel analysis at 50%), calculated with all the recorded positions with instantaneous speed < 9km/hr, is represented in gray; the islands of the granitic archipelago in black; and the boundary of the granitic bank with a broken line. On the top right corner, the position of Aride Island in relation to the Africa continent is shown by a star.

Chick weight averaged 198.2 g (Range = 34.4-445.2, $n = 9$). Using a log fit, the maximum distance covered by breeders during foraging trips was positively related to the chick weight (linear regression: $t = 3.35$, $R^2 = 0.616$, $P = 0.012$). The variance accounted for chick weight was 61.6%.

Discussion

During the chick-rearing phase, several pelagic bird species perform a dual foraging strategy, alternating short trips used for chick provisioning and longer trips mainly used for self-provisioning (Weimerskirch *et al.* 1994). This behavior allows birds to balance the need of regularly visiting the colony on the one hand, with accessing better foraging areas farther from the colony on the other hand. Normally, during the early chick-rearing period, chicks need to be fed often and regularly, forcing breeders to make short trips and, in some cases, to exploit less profitable areas than those exploited with longer trips (see Cecere *et al.* 2013). Congdon *et al.* (2005) have described a dual foraging strategy for Wedge-tailed Shearwaters breeding on Heron Island, Australia, with foraging adults performing short-trip cycles of multiple 1- to 4-day trips followed by a single long trip of approximately 8 days. In the current study, only one trip out of 13 (7.7%) lasted more than 4 days (a second one may have lasted more than 4 days, but the GPS ran out of battery power before individual returned). The infrequent occurrence of long lasting foraging trips (> 4 days), normally used by most shearwater species for self-provisioning (Weimerskirch *et al.* 1994), could be due to the opportunity for self-provisioning during shorter trips (≤ 4 days). A specific study analyzing the length of foraging trips carried

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out throughout the whole chick-rearing period will be required to test this hypothesis. It is possible that long lasting trips may occur more frequently during the late chick-rearing period. This hypothesis is supported by the positive relationship between chick weight and maximum distance covered by adults during their foraging excursions.

Despite the limited sample size, it is clear that birds always flew to the east, presumably to forage. The ability of long-lived seabirds to head from the breeding colony toward favored and profitable foraging areas is well known (Weimerskirch 2007). In this study, all tagged birds exploited the same area located just beyond the granitic bank in an upwelling area characterized by higher values of primary production compared to the surrounding marine habitat.

The exploited area size was much smaller than that identified during late chick-rearing for Wedge-tailed Shearwaters breeding on Aride Island (3,313 vs. 160,000 km^2; Catry *et al.* 2009). Considering the similar sample size of the two studies (10 and 9 birds respectively), the difference might be due to the higher accuracy of GPS technology, compared to that of GLS technology used by Catry *et al.* (2009). However, since we cannot exclude the dual foraging strategy in the Aride Island population, the difference in size could also be due to the different period investigated. Late chick-rearing could indeed be characterized by longer trips, which could allow birds to explore larger areas, although longer trips do not necessarily imply the exploitation of a larger area since birds could simply travel to a more distant, concentrated region to feed.

Overall, GPS technology proved to be a good tool to study this relatively small shearwater species. Nevertheless, we have to note that a good number of individuals managed to peel off the device (29%), which was lost despite the experience of the authors with GPS deployment. Most of the re-trapped tagged Wedge-tailed Shearwaters, indeed, had pieces of the Tesa tape removed and in two cases the device was about to fall off during the re-trapping.

Despite the small sample size, all tracked birds went to such a consistent fishing ground that we believe our results could be considered reliable. Despite being rated as a species of Least Concern according to the IUCN red list, there is evidence of population decline among Wedge-tailed Shearwaters (BirdLife International 2010). The identification of key foraging areas, like those used by breeders from Aride Island during early chick-rearing, is a priority for habitat management and conservation action plans for pelagic seabirds.

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