

**A preliminary report of ongoing research of the ecology of Black-capped Petrel (*Pterodroma hasitata*) in Sierra de Bahoruco, Dominican Republic – I: GPS tracking of breeding adults**



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# 1 Introduction

Due to their extensive use of the marine habitat and reliance on terrestrial habitat during the breeding period, pelagic seabirds interact with both marine and terrestrial threats, making them one of the most threatened groups of birds globally (Croxall et al. 2012). While localized terrestrial threats are commonly studied and conservation actions are often implemented to mitigate their effects, threats and processes affecting pelagic seabirds in the marine environment are generally poorly understood and effective conservation actions are more challenging to implement there. Defining and qualifying at-sea threats to seabirds requires knowledge of foraging habits (location, diet and behavior) and movement patterns. Spatial data are typically obtained either through at-sea observations or through individual tracking studies. In the western North Atlantic, large-scale marine spatial data for pelagic seabirds have been historically limited to ship-based surveys (O’Connell et al. 2009). While such surveys have the advantage of recording the presence of all species and age-classes of pelagic seabirds at specific locations and time periods, they are logistically constrained in space and time and they are unable to link breeding locations and marine use. Individual tracking studies, in contrast, offer a more active approach to gathering seabird movement data that are not limited by *a priori* geographical assumptions (Wakefield et al. 2009). Individual tracking also provides a direct link between terrestrial and marine sites of importance for pelagic seabirds, thus allowing conservation actions to be geographically targeted. However, tracking studies are restricted in extent by limitations in the size and cost of tracking devices. In the Caribbean region, data on the foraging habits and movements of pelagic seabird species are scarce although recent tracking studies of Procellariidae described marine movements that expanded outside the previously identified range for these species (Madeiros et al. 2013, Jodice et al. 2015, Precheur et al. 2016). In particular, Jodice et al. (2015) showed that Black-capped Petrels (*Pterodroma hasitata*) provisioning chicks utilized the upwelling waters of the south Caribbean Sea off Colombia and Venezuela (Guajira Peninsula), an area where they had rarely been observed. Until then, it had been suspected that breeding petrels typically commuted to the western edge of the Gulf Stream, where they are commonly observed during ship-based surveys (Haney 1987, Simons et al. 2013).

In the spring of 2018, the Principal and co-Principal Investigators partnered to study the foraging ecology of Black-capped Petrel. The Black-capped Petrel (also known regionally as *Diablotin*) is a gadfly petrel endemic to the Caribbean. The species has a fragmented and declining population, is considered endangered throughout its range (BirdLife International 2016), and has recently been proposed for listing under the Endangered Species Act by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 2018). Population estimates based on at-sea observations range from 2,000 to 4,000 individuals, with a fragmented breeding population estimated at 500 to 1,000 pairs (BirdLife International 2018). While historical records and recent surveys suggest possible nesting populations in Cuba and Dominica, the only breeding areas confirmed to date are located on Hispaniola (Simons et al. 2013). All known nesting sites (Massif de la Hotte and Massif de la Selle in Haiti, and Sierra de Bahoruco and Cordillera Central in the Dominican Republic) are in mountainous areas, 1,500 – 2,200 m above sea level. Conservation concerns at nesting areas include but are not limited to habitat loss, habitat degradation, and predation by non-native species. Black-capped Petrels build their nest underground, in montane forests characterized by steep terrain with decaying vegetation or loose rocks and soil allowing for

burrow excavation. Since the early 2010's, nesting areas are monitored annually by Grupo Jaragua in the Dominican Republic and Haiti, and, since 2018, by Société Ecologique d'Haiti (now Jeunes en Action pour la Sauvegarde de l'Ecologie en Haïti) and Environmental Protection in the Caribbean in Haiti.

At sea, the expansive marine range of the species exposes it to many conservation threats including fisheries activity, offshore energy development, marine pollution including mercury bioaccumulation, and climate change (Goetz et al. 2012). Such disturbances at sea have been under-studied although they are likely to impact the survival of the species (Simons et al. 2013). Therefore, the goal of this project was to gather fine-scale data on individual movements of Black-capped Petrels breeding in the Sierra de Bahoruco, Dominican Republic. Our objective was to use GPS tracking devices to identify the foraging behavior and the locations and environmental characteristics of foraging areas of breeding Black-capped Petrels in the Caribbean Sea. We provide results from the deployment of nine remote-download GPS loggers on breeding Black-capped Petrels from Sierra de Bahoruco during April 2018.

## **2 Methods**

### **2.1 Study area**

The study area included the Black-capped Petrel nesting area of Loma del Toro (18.3°N, 71.7°W), on the Sierra de Bahoruco ridge, Dominican Republic (Figure 1). This site is ca. 30 km inland, 2000-2,200 m in elevation and is characterized by steep slopes and ravines, and ridges with montane forests of Hispaniolan pine. Since 2010, approximately 45 Black-capped Petrel burrows have been discovered in the area's ravines of dense and humid understory vegetation, under leaf litter or among boulders (Figure 2). These nest sites are sparsely distributed but occur in loose clusters (e.g., several nests within 100 m of each other).

### **2.2 Data collection**

From 13 – 18 April 2018, we set traps prior to sunset in burrows where a chick was present or where we observed strong evidence of nesting activity (i.e. strong odor, fresh breast feathers or feces at burrow entrance). We checked traps at first light the next day. The traps (ca. 0.5 m long with an opening ca. 15 by 15 cm) were constructed from fine mesh wire, with a one-way door. Each captured bird was assessed for general condition, weighed and measured (tarsus, wing chord, exposed culmen length, and culmen depth at gonys), and banded on the right leg with a metal USGS Bird Banding Laboratory band (size 3). Breast feathers were collected for genetic sexing and future analyses of stable isotopes. Photographs of the birds' profiles were taken and used to classify the color morph of each adult on a continuous scale ranging from -3 (light phase) to +3 (dark phase; adapted from Lamoreaux 2013), and on the discrete scale proposed by Howell and Patteson (2008). We used remote-download GPS loggers (Mataki-LITE, Debug Innovations, Cambridge, UK; 5 m spatial precision; 3.5 g) powered with a 150mAh lithium-ion battery (TinyCircuits, Akron, USA; 3.8 g). Waterproofed GPS loggers (using light-weight heatshrink tubing F4(Z), Heatshrink.com, Ogden, USA) weighing ca. 8 g were attached with 2-part epoxy, 3 strips of TESA cloth tape, and a 0.2 mm zip-tie to the underside of the 4 central rectrices near the base. Only birds with

a body mass > 380 g were tagged. The handling process lasted less than 15 minutes and all birds were returned to their burrows. Subsequent surveys of burrows occurred in June and July to establish chick survival.

GPS tags were programmed to turn on 24h after deployment, when the birds were expected to be at sea. Doing so avoided draining the battery while birds were in their nests (i.e., underground). Based on results from Jodice et al. (2015), we expected foraging trips to last ca. 10-15 days thus GPS loggers were set to record GPS locations every 30 minutes in normal power mode (see Appendix A and B for details of the GPS script) to allow for a battery life of ca. 21 days. Individual base-stations (Mataki-CLASSIC, Debug Innovations, Cambridge, UK) were placed near each cluster of sampled nests and were set to remote-download tracking data from the GPS-loggers via UHF radio (916mHz) as birds returned after foraging trips (see Appendix A and B for details of the radio script). Each base-station was powered with a 5.5W solar panel and a 12,000mAh lithium-ion battery (Voltaic Systems, Brooklyn, USA; see Appendix C for details on base-station set-up). We considered re-trapping birds fitted with loggers but this would have required daily monitoring of all nests for the duration of the tracking period, which was prevented by the lack of manpower for such a long duration. Also, daily visits to nest sites would have caused damage to the fragile nesting habitat of soft soil and/or loose rocks surrounding burrows.

Authorizations to work within the Sierra de Bahoruco National Park, Dominican Republic, were granted by the Ministerio de Medio Ambiente y Recursos Naturales. All animal manipulations were performed under Clemson University's Animal Care and Use protocol AUP2018-005. Biological samples were collected with authorization from the Dominican Museo Nacional de Historia Natural. Banding was authorized by the USGS Bird Banding Lab (#22408).

### **2.3 Morphological analysis**

While an in-depth study of variations in Black-capped Petrel morphometrics is outside the scope of this report, we compared the morphometrics of adult Black-capped Petrels captured in Loma del Toro, Dominican Republic in 2014 (Jodice et al. 2015) and 2018 (this study) with adults collected in Gulf Stream waters from 1978-1985 (D. Lee, summarized in Simons et al. 2013, and used in Howell and Patteson 2008; not including specimens categorized as juveniles). Statistical differences were calculated with unpaired two-sample t-tests (for unequal variance).

### **2.4 Preliminary analysis of tracking data**

Tracking data were downloaded from base-stations during subsequent visits in June 2018. Track characteristics were calculated using the R package *adehabitatLT* (Calenge 2006). Nest visits by tagged birds were included as fixed locations. We calculated the distance between each location and the closest coastline, and distance to the nesting area in an equidistant cylindrical projection centered on tracked locations using mean longitude and latitude as central meridian and parallel. Locations with low spatial precision (horizontal dilution of precision,  $hdop > 20$ ) or with unrealistic speeds ( $> 90 \text{ km h}^{-1}$ ) were filtered out. Because GPS locations were not always recorded on schedule (83.7% of recorded locations occurred at 30 minute intervals), we interpolated missing locations every 30 minutes (function *redisltraj*



in *adehabitatLT*). When gaps of missing locations were longer than 2 hours, we filtered the interpolated locations to only keep those that occurred within 1 hour of existing GPS data. We used dynamic residence in space and time (Torres et al. 2017) to identify and classify all resulting locations as either corresponding to transit (residual = 0), resting (residual < 0), or foraging (area-restricted search: residual > 0). Briefly, the Residence in Space and Time (RST) method uses normalized values of Residence Time (time spent by a tracked animal within a circle of pre-defined, constant radius  $R$  along its track) and Residence Distance (distance moved within the circle) to categorize behavior patterns that are time-intensive (rest), time- and distance-intensive (foraging with area-restricted search), or reduced in time and distance (transit).  $R$  was dynamically selected for each tracked bird individually and categorizations were performed at the individual level. We tested behavior-marked data for differences in behavior between individuals (non-parametric Kruskal-Wallis test by rank, followed by pairwise comparisons using a Wilcoxon test) and for an influence of time of day (day vs. night, using a non-parametric, unpaired Wilcoxon test) on RST residual values.

As a preliminary analysis of at-sea habitat variables and potential threats, we explored correlations between movement data, environmental oceanic variables and fisheries and hydrocarbon datasets (Table 1; Appendices D and E). A thorough analysis of marine habitat selection and threats will occur when results from our concurrent molecular diet analysis are known. All analyses were performed in R (R Core Team 2016).

## 3 Results

### 3.1 Captures and data collection

Twelve chick-rearing adult petrels were captured at Loma del Toro between 15 and 21 April 2018 (Table 2). Feather status of chicks and data from nest checks suggest that all chicks were ca. three weeks post hatch. GPS loggers were deployed on nine birds. Mean body mass of captured birds was 399 g (345-450 g, sd = 31.6). Equipped birds ranged in mass from 385 to 450 g hence GPS loggers ranged from 2.1 to 2.5% of body mass. All captured birds were of dark color phase, ranging from 0-intermediate/d (1 individual) to +3-dark morph/f (4 individuals; Table 2 and Figure 3). Mean color phase was +2 (sd = 0.9, cv = 0.45). Handling time from capture to release averaged ca. 11 minutes (8-16 min, sd = 2.7). Birds 110<sup>1</sup> and 109, both members of one pair (nest A), were caught during the same trapping session and both were equipped. Bird 107 was captured in the same nest (B) as Bird 1633-02638 in Jodice et al. (2015): since it was not already banded, Bird 107 is believed to be the breeding partner of Bird 1633-02638. Within breeding pairs, birds caught in nest A appeared similar in size (Table 3). However, size appeared to differ between birds caught in nest B (Bird 1633-02638 had higher mass, longer tarsus, and longer and deeper culmen).

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<sup>1</sup> Equipped birds are referenced by their GPS tracking numbers, and birds that were not equipped or were part of another study are referenced by their metal band numbers (Table 2).

Adult Black-capped Petrels captured in this study were not significantly different in mass ( $\bar{x}_{2018(12)} = 398.8$  g vs  $_{2014(4)} = 382.5$  g;  $p = 0.47$ ), culmen length ( $\bar{x}_{2018(12)} = 32.10$  mm vs  $_{2014(4)} = 31.97$  mm;  $p = 0.85$ ), culmen depth ( $\bar{x}_{2018(12)} = 13.22$  mm vs  $_{2014(4)} = 13.20$  mm;  $p = 0.93$ ), or tarsus length ( $\bar{x}_{2018(12)} = 39.45$  mm vs  $_{2014(4)} = 39.40$  mm;  $p = 0.92$ ), than adults captured by Jodice et al. in 2014 (Tables 4 and 5) and were therefore grouped in further analyses. All birds captured at Loma del Toro in 2014 and 2018 had a significantly smaller mass ( $\bar{x}_{Loma(16)} = 394.7$  g vs  $\bar{x}_{monograph(59)} = 437.7$  g;  $p < 0.005$ ), culmen length ( $\bar{x}_{Loma(16)} = 32.07$  mm vs  $\bar{x}_{monograph(59)} = 32.93$  mm;  $p = 0.005$ ), and culmen depth ( $\bar{x}_{Loma(16)} = 13.21$  mm vs  $\bar{x}_{monograph(59)} = 15.54$  mm;  $p < 0.005$ ) than all birds captured in the Gulf Stream. Birds collected at sea during breeding months (birds collected from March to August) were significantly lighter than birds collected at sea during non-breeding months (September to February:  $\bar{x}_{breed(33)} = 412.2$  g vs  $\bar{x}_{non-breed(31)} = 460.8$  g;  $p < 0.005$ ). There were no statistical differences in culmen length and depth between these two groups. Birds collected at sea during the breeding months were not significantly heavier than birds confirmed breeding captured at Loma del Toro ( $t = 1.36$ ,  $df = 41.64$ ,  $p = 0.18$ ) but differences in culmen length ( $\bar{x}_{Loma(16)} = 32.07$  mm vs  $\bar{x}_{non-breed(31)} = 32.97$  mm;  $p = 0.02$ ), and culmen depth ( $\bar{x}_{Loma(16)} = 13.21$  mm vs  $\bar{x}_{non-breed(31)} = 15.56$  mm;  $p < 0.005$ ) were statistically different between these two groups.

On 2 June and 24 July 2018, burrows of tracked individuals were checked as part of a colony-wide survey of productivity: all burrows included in this study were active with chicks near fledging age, suggesting that chicks were being provisioned and that no bird sampled in this study abandoned. In one burrow considered for trapping but not selected because it was too far away from the cluster of other trapped burrows, a PTT tracker from the Jodice et al. (2015) study was recovered on 14 April 2018 and confirmed to be from Bird 1633-02640 that was tracked back to the colony in November of 2014. This individual was captured in the same burrow in 2014.

On 19 and 20 April 2018, two base-stations (201 and 203) were deployed to receive data from four loggers each and one base-station was connected to only one logger (station 202, to bird 107; Table 2). All three base-stations were recovered on 2 June 2018 and the tracking data they had recorded were downloaded on 3 June 2018. Voltage levels for the period of deployment indicate that base-stations had ample power supply for the period of deployment (Appendix C). Of the nine deployed GPS loggers, only three (107, 110 and 111) reported to a base-station during the deployment period. Base-station 201 did not receive data from any of its four assigned loggers; 202 received data from its single assigned logger; and 203 received data from two of its four assigned loggers. The three birds for which data were recovered were tracked for a single provisioning trip lasting 8 to 11 days (Table 6). Although they had been scheduled to do so, the GPS loggers did not record location data continuously: as a result, an average of 12.5 locations per day were collected (107 = 15.9 locations per day, range 4-26; 110 = 12.0 locations per day, range 6-21; 111 = 12.4 locations per day, range 1-27) as opposed to a predicted 48 locations per day. No locations were filtered out because of poor spatial precision or unrealistic speed.

### 3.2 Residence in space and time

Using the dynamic scaling approach to determine  $R$  for each track ( $R_{107} = 5.50$  km;  $R_{110} = 6.20$  km; and  $R_{111} = 9.05$  km), RST behavioral classification resulted in 26.1% of locations being categorized as transit (107: 21.7%; 110: 22.1%; and 111: 37.0%), 34.5% as foraging (107: 28.8%, 110: 40.7%; and 111: 37.0%),

and 39.4% as rest (107: 49.5%; 110: 37.1%; and 111: 26.0%). Behaviors were significantly different among individuals (Kruskal-Wallis:  $\chi^2 = 33.595$ ,  $p < 0.005$ ). Bird 107 allocated more time to rest compared to birds 110 and 111 (Wilcoxon test:  $p_{107/110} < 0.005$ ;  $p_{107/111} < 0.005$ ;  $p_{110/111} = 0.26$ ). Behavior was not influenced by time of day (Wilcoxon test:  $p_{\text{day (328)}/\text{night (159)}} = 0.29$ ).

### 3.3 Movements

Hereafter, capital letters refer to oceanographic features listed in Figure 1; described behaviors are inferred from RST residual values.

Bird 107 departed the colony on the night of 19-20 April (Figure 4.a) and was located over Beata Ridge (H) throughout the remainder of the day, where only transit and resting behaviors were recorded. On the evening of 20 April, Bird 107 moved northwest to the Jamaica Channel, where it remained for the subsequent seven days. Area-restricted search occurred on both sides of the Jamaica Channel, primarily over the seamounts of Formigas (F) and Albatross (G) Banks. On 27 April, Bird 107 moved towards Hispaniola and was located off Haiti's Sud-Est province ca. 12h00 LMT of 28 April. It remained ca. 8 km from the coast (range: 5.6 – 11.8 km) until ca. 19h30 LMT, when it flew inland to the nest site. It travelled over land in the west-northwest direction, ca. 2 km north of the villages of Anse à Cochon and Boucan Guillaume, Haiti, and appears to have followed the thalweg of the Río Pedernales to Loma del Toro, Dominican Republic (Figure 4.b). It arrived at the colony ca. 22h00 LMT on 28 April. Total trip distance was 2,057 km, with a maximum distance to the colony of 445 km. Bird 107 sustained a maximum average speed of 46 km h<sup>-1</sup>.

Bird 110 departed the colony on the night of 20-21 April (Figure 4.c) and engaged in foraging and resting behaviors over the Beata Ridge. From 22 to 24 April, it foraged north of the Aruba Gap (I). From 25 April to the end of the recorded period (i.e. 28 April), it foraged in waters west of the Guajira Peninsula (J) ca. 110 km offshore (range: 47.5 – 172.4 km), with a day trip to waters west of the Aruba Gap (27 April). Bird 110 returned to the nesting area at ca. 22h30 LMT on 30 April. Total trip distance was 2,756 km, with a maximum distance to the colony of 765 km. Bird 110 sustained a maximum average speed of 39 km h<sup>-1</sup>.

Bird 111 departed the colony on the night of 21-22 April (Figure 4.d). On the evening of 22 April, it occupied waters south of the Jamaica Channel. On the morning of 23 April, it foraged north of the Channel before travelling to the waters off the southern coast of Cuba: it displayed a resting behavior during 8.5 h ca 24.5 km from the coast (range: 24.3 – 24.6 km), south of El Verraco and the Baconao National Park. It departed during the night of 23-24 April and foraged over the Windward Passage (E) until the evening of 24 April. From 25 to 28 April, Bird 111 occupied waters of the western Sargasso Sea from South to North. It reached the northernmost point of the trip on 27 April (latitude 31.79°) while in pelagic waters, midway from Georgia, USA, to the west and Bermuda to the east. On 28 April, Bird 111 foraged north of the Blake Spur (D), 400 km to the west of its previous location. It returned to the colony at ca. 23h00 LMT on 1 May. Total trip distance was 4,651 km, with a maximum distance to the colony of 1503 km. Bird 111 sustained a maximum average speed of 49 km h<sup>-1</sup>.

## 4 Discussion

### 4.1 Morphometrics

Seabird morphometric measurements can be used to infer intraspecific differences such as sexual dimorphism (Fairbairn and Shine 1993, Navarro et al. 2009, but see Croxall 1995) or phylogeny (Bull et al. 2004, Judge et al. 2014). In the Black-capped Petrel, sexual dimorphism has been reported in culmen depth only, with males having a significantly deeper bill than females (Howell and Patteson 2008 and Tables 4 and 5). Breeding birds captured at Loma del Toro in 2014 and 2018 were smaller in mass, culmen length, and culmen depth than all birds captured in the Gulf Stream, although the strong statistical difference in culmen depth might be biased by different measurements methods or personnel (measurement location was not reported in Simons et al. 2013). However, when birds reported in Simons et al. (2013) were grouped by season of capture (breeding: birds collected from March to August; non-breeding: birds collected from September to February) to take into account the effect that breeding might have on the mass of adults raising a chick, the body mass of birds captured at sea during breeding months was less than the mass of birds captured at sea during non-breeding months. Culmen length and depth showed no statistical differences between these two groups. The mass of birds collected at sea during the breeding months was not significantly different from that of confirmed breeding birds captured at Loma del Toro, suggesting that the former group was likely breeding at the time of capture. These results suggest that lighter birds captured at sea in Gulf Stream waters may have been breeding birds. Also, although differences in culmen length could occur if sampled birds were from different sub-populations, the differences reported in culmen measurements, while statistically significant, may not be biologically relevant since they were of 1 mm and 2 mm respectively, hence small enough to have been caused by differences in measurement tools, location, or personnel.

Although two color phases exist for the Black-capped Petrel and sexually dimorphic plumage may be important for courtship interactions (Simons et al. 2013), Howell and Patteson (2008) did not find an appreciable difference in the color phase of both sexes, instead proposing that differences in color phases represent distinct populations. Supporting Howell and Patteson's hypothesis, the analysis of mitochondrial DNA by Manly et al. (2013) suggested that the existence of separate phylogenetic groups was consistent with breeding isolation of the dark and light morphs. Although petrels captured in this study showed variation in the extent of the dark feathering, they were all of dark phase type and most were of the darker morph. These results are consistent with hypotheses that the Hispaniola population is likely to be of dark type and that dark morph petrels observed at sea are likely to originate from this population.

### 4.2 Data acquisition

GPS logging rates were lower than planned, with an average of 12.5 locations per day instead of the scheduled 48 locations per day. Two possible reasons for reduced performance include excessive cover of the GPS antenna and/or the unfavorable position of GPS satellites at the time of recording. Each is discussed in turn.

We secured tags using tape and heat shrink tubing and centered the mass of the logger as close to the base of the tail as possible and on the ventral side between the undertail coverts and the rectrices, with the GPS antenna facing dorsally. We selected this attachment point to avoid rectrix breakage and undue movement of the tag while the bird was in flight. We did not locate loggers on the dorsal side of the tail so as to avoid covering the uropygial gland. A similar tracking study successfully used Mataki-LITE deployed on the back of Atlantic Puffins (*Fratercula arctica*, Butcher, Royal Society for the Protection of Birds, pers. com.) therefore we suspect that our attachment location on the underside of the tail had a negative impact on the recording rate. Successful logging also can be influenced by the location of GPS satellites at the time of recording. Indeed, while GPS devices used by the general public have an ample supply of power that allows them to always be in communication with the network's satellites ("hot start"), low-power wildlife tracking devices only activate GPS communication at the time of logging ("cold start"). Thus the amount of time required for a successful GPS logging (which is limited *a priori* to optimize power consumption) is affected by the location of GPS satellites at the moment of the cold start. Although it is possible to extend the time period allocated to successfully log a GPS location, this would drastically increase power consumption. Therefore, we recommend that future deployment prioritize attachment location over extending the GPS "ON time". Future deployments may consider an attachment above the tail particularly if tag mass can be decreased and if the uropygial gland is not covered. Further, to avoid undue stress to the rectrices, the center of gravity of the logger should be as close to the rump as possible.

### 4.3 Data recovery

The rate of data recovery was poor as only three of nine deployed GPS loggers transmitted data to their respective base-stations. Several possibilities exist for the lack of transmission, including but not limited to (1) water penetrating the waterproofing, (2) death of tracked bird, (3) early loss of logger, (4) early drain of logger battery, and (5) lack of contact with the base-station. We suggest that (1) and (2) were unlikely. We performed tests prior to deployment to ensure that the waterproofing technique used in this study was resistant enough to sustain repeated immersions. Our nest monitoring also demonstrated that chicks of all tracked petrels were alive and in good condition in June and July, suggesting that chicks were being provisioned and hence that tagged birds did not die during the tracking period.

Attachment failure may have occurred due to either failure of the tape or rectrices breaking. Tape failure seems unlikely given previously successful deployments on seabirds including *Pterodroma* spp. for extended periods of time using the same type of tape (Imber et al. 2005). Furthermore, we reinforced our attachments with epoxy and a zip-tie. Other researchers have reported loss of loggers when the rectrices that support the loggers break off during the tagging period. For example, both Soanes et al. (2015) and Neuman et al. (2018) reported rectrices breaking in Sooty terns (*Onychoprion fuscatus*) carrying loggers 1.2 and 1.7% of body mass. An alternative to attaching the logger on the ventral side of the tail that may lessen the probability of the rectrices breaking is to secure the logger on the dorsal side of the bird, either at the base of the tail or along the back (Guilford et al. 2008 for Manx shearwater *Puffinus puffinus*). A dorsal attachment, however, exposes the logger to abrasion along the roof of rocky burrows or entanglement in hanging roots when the bird moves into and out of the nest

site, both common attributes of nests in our study area. Future deployments may consider dorsal deployments on birds nesting in large sod burrows while ventral attachments along the tail might be reserved for birds nesting in smaller burrows with rock roofs or overhanging roots.

Two other possible reasons for the poor rate of data recovery include an early drain of the logger battery and a lack of contact with the base-station. Battery power in remote-download GPS loggers such as Mataki-LITE is drained primarily on: (1) activation of the GPS module to 'listen' to communications from the network's satellites, and (2) use of the UHF radio to communicate with the base-station and, later, upload tracking data. Taking these characteristics into account, we had written the logging script to optimize battery use through a 25-km geofence to trigger UHF radio communications and a low-voltage mode (see Appendices A and B for more details). Based on recovered tracking data, it appears that none of the functioning loggers had entered the low-voltage mode during the ca. 10 days at-sea though two of them (110 and 111) had battery levels below the low-voltage threshold at the time of uploading data to the base-station (Table B.2). Because logger battery levels are only recorded when they send a 'heartbeat' to the base station, it is unclear if these low battery levels had (a) been reached earlier during the tracking period without triggering the low-voltage mode, (b) had triggered the low-voltage mode but GPS data were not recorded, or (c) resulted from a power drain due to radio communications. Future deployments may consider a simultaneous logging of GPS locations and battery levels, and GPS logging frequency may have to be decreased to optimize power consumption.

Lastly, loggers that did not transmit tracking data may not have established contact with their respective base-stations despite having sufficient battery voltages. Radar surveys near breeding colonies showed that Black-capped Petrels sustain flight speed  $>50 \text{ km h}^{-1}$  (Brown 2013a), and may reach speeds up to  $70 \text{ km h}^{-1}$  when arriving at colonies (Rupp, Grupo Jaragua, pers. com.). Also, camera trapping surveys of breeding petrels showed that petrels enter their burrows within seconds (Rupp, Grupo Jaragua, pers. com.). Furthermore, camera trapping has demonstrated that provisioning petrels stay at the nest site for  $30.7 \pm 8.9$  minutes (Jodice et al. 2015), including  $<5$  minutes outside the burrow. Pre-deployment trials showed that loggers placed at a burrow's entrance successfully communicated with base-stations but loggers placed 1 m within the burrow did not. The 2-minute 'heartbeat' of the GPS tag activated inside the 25-km geofence to optimize power use vs. successful radio communication should have been sufficient to upload tracking data. Nevertheless, loggers that had failed to trigger the 25-km geofence or that had already entered the low-voltage mode were less likely to be within range of the base-station (ca. 200 m) for long enough to send a successful heartbeat. Future deployments may consider a wider geofence radius and a higher heartbeat frequency in low-power mode.

#### **4.4 Behavior categorization**

As biologging devices have become miniaturized and less expensive (Cagnacci et al. 2010), the proliferation of animal tracking studies has led to the development of several analytical frameworks intended to distinguish behavior patterns. Various methods have been adapted to or specifically designed for the study of spatial ecology in seabirds and can be used to detect active (such as travel to foraging areas and search within those areas) from passive behaviors (inactivity, determined by a lack of movement). While all of these approaches are based on metrics calculated from spatial observations,

these methods can differ in the way they identify and categorize behaviors of interest (Bennison et al. 2018). Although more statistically and programmatically complex methods may be more apt to distinguish nuanced differences in behaviors (e.g. hidden Markov models, speed/tortuosity thresholds, k-means clustering), for this preliminary study, we chose to examine tracking data with the Residence in Space and Time approach (RST; Torres et al. 2017). Building upon and refining the method of *first passage time*, the RST approach incorporates a measure of residence distance to the existing metrics of residence time, and identifies three types of behavior patterns: transit (low time and distance residency), area-restricted search (high time and distance residency) and rest (high time and low distance residency). Unlike other methods that require *a priori* knowledge of behavior (e.g. thresholds) or more regular data in space and time (e.g. hidden Markov models), the RST approach is better adapted for exploring movement data and preliminarily annotating behaviors (Torres et al. 2017). Given our small sample size ( $n = 3$  individuals), we could visually assess the results of the behavior classification as a means to provide verification. Fast directional movements were categorized correctly as transit ( $\bar{x}_{\text{transit speed}} = 24.4 \text{ km h}^{-1}$ ). In general, the approach also correctly made a distinction between bouts of slow directional movement (rest:  $\bar{x}_{\text{rest speed}} = 5.1 \text{ km h}^{-1}$ ) and bouts of slow turning movements (area restricted search:  $\bar{x}_{\text{ARS speed}} = 10.0 \text{ km h}^{-1}$ ). The RST approach tended to over-categorize slow turning movements, however, a behavior typical of approaches relying upon *first passage time* (Bennison et al. 2018). Despite this shortcoming, the general pattern of model-induced behaviors was consistent with at-sea behavior for the species (Haney 1987).

At sea, Black-capped Petrels are active during the daytime, with peaks in activity from 07h00-09h00 and 17h00-19h00 (Haney 1987). The prominence of pelagic Cephalopoda in their diet also suggest, however, an adaptation for crepuscular or nocturnal feeding given that this prey item undergoes nocturnal diel migrations (Simons et al. 2013). We did not observe differences in behavior between day and night but this result may have been influenced by the unbalanced distribution of observations during daytime ( $n = 328$ ) compared to nighttime ( $n = 159$ ).

In two instances, tracked Black-capped Petrels displayed a behavior consistent with coastal rafting. Several species of Procellariidae exhibit coastal rafting wherein individuals flock tightly on the water offshore of breeding colonies, waiting for dusk prior to coming ashore (e.g. Brooke 1990, Ainley et al. 1997). Although Black-capped Petrels have mostly been observed in resting rafts in offshore conditions (Lee pers. obs., cited by Simons et al. 2013), Rosenberg (2004) observed staging petrels within sight of the coast of Cuba. Keith (2009) lists observations of Black-capped Petrels made from the coast of southern Haiti and the western Dominican Republic though he does not state if birds were flying or rafting. Birds 107 and 111 spent 7.5 h ca. 8 km off southwest Haiti, and 8.5 h ca. 24 km off southern Cuba, respectively, resting close to shore in the proximity of known or suspected breeding colonies. Both birds arrived in the middle of the day and departed after sunset, with Bird 107 subsequently flying back to the breeding colony in Sierra de Bahoruco.

## 4.5 Movements, habitat use, and macro-exposure to threats in the marine environment

This is only the second study to document the at-sea movements of breeding Black-capped Petrels, and the first to track individuals at a fine spatial and temporal scale. Although limited in scope, our results confirm that provisioning Black-capped Petrels often travel between 2,000 and 4,000 km during foraging trips lasting up to 11 days. Our study validates the extensive use of the Caribbean Sea by breeding Black-capped Petrels first described by Jodice et al. (2015) while also supporting the hypothesis that petrels nesting on Hispaniola use Gulf Stream waters during the breeding period (Haney 1987, Simons et al. 2013). Indeed, two GPS-tagged petrels stayed in the Caribbean basin, utilizing the seamounts of the Jamaica Channel (Bird 107) and the continental shelf off the Guajira Peninsula (Bird 110) while the third (Bird 111) frequented waters between the eastern boundary of the Gulf Stream and the Sargasso Sea. In the 2014 tracking study, only one individual (Bird 176) utilized Atlantic waters during the breeding season, on one provisioning trip out of five and directly following capture. Since all of the tracked petrels were of dark color phase, our results and those of Jodice et al. (2015) are consistent with hypotheses that dark morph Black-capped Petrels commonly use the Caribbean basin during the breeding season. This assumption also is consistent with observations by Howell and Patteson (2008) that dark morph petrels are less common in Gulf Stream waters during the breeding season compared to the non-breeding season.

For all three tracked Black-capped Petrels in this study, most foraging occurred in pelagic waters generally governed by mesoscale processes. Preliminary mapping of environmental variables suggests, however, that individuals may have used different foraging strategies. For example, Bird 110 used colder waters of the Guajira upwelling and the outflow of Lake Maracaibo (Figures D.1.a and b, in Appendix D) while Bird 111 foraged at cyclonic fronts east of the Gulf Stream (Figure D.1.c). Upwelling and pressure fronts likely concentrate prey for surface predators by migrating nutrients up through the water column and by concentrating primary producers and consumers at the edge of eddies, respectively. These processes thus enhance prey density and availability for foraging Black-capped Petrels. These results complement Haney's (1987) observations of Black-capped Petrels at kinetic eddies and local upwelling along the eastern edge of the Gulf Stream. In contrast, Bird 107 remained in the Jamaica Channel, an area of sea mounts and mixed waters, and its habitat use did not appear to correlate with mesoscale environmental variables (Figures 4.a and D.1). These areas used by Bird 107 are within 25-50 km of where Shirihai et al (2010) attracted 46 individual Black-capped Petrels with fish oil and chumming. In homogenous tropical systems where the aggregation of prey is not governed by ephemeral, though predictable, phenomena such as upwelling or climatological fronts, seabirds may instead rely on large predatory fish to herd and drive schools of forage fish to the surface (facilitated foraging; Miller et al. 2018). In the South Atlantic Bight, Haney (1987) observed Black-capped Petrels feeding over such aggregations, alone or with other seabird species, a behavior that Bird 107 may have displayed in the Jamaica Channel.

One tracked petrel was recorded flying inland to the Sierra de Bahoruco along a flight path that was within 5 km of the Río Pedernales valley leading towards the nesting area (Figure 4.b). Although our data were not of a fine enough temporal resolution to clearly demonstrate use of that valley, it is not



unreasonable to posit that the bird's flight path followed the general path of the valley. Indeed, Ainley et al. (1997) report that Hawaiian Petrel flying to the colony followed main river beds and Simons et al. (2013) cite observations of Black-capped Petrels flying inland up a valley in Cuba. Radar surveys performed along the Río Pedernales valley and other petrel flyways on Hispaniola also verified that petrels almost exclusively used valleys as flyways (Brown 2013b).

Exposure to threats can occur at different geographical scales. Burger et al. (2011) define macro-exposure to a marine-based threat as the occurrence of the species of concern within the geographical area of interest (e.g., the broad area where the threat occurs). In the Atlantic and Caribbean basins, it appears that foraging and commuting ranges of Black-capped Petrels overlap at the macroscale level with areas used by pelagic fisheries (Figures D.2. and D.3). For example, the area west of the Guajira upwelling utilized by one bird in this study and by all birds in Jodice (2015) also supported trawling and both drifting and fixed longline fisheries (Figure D.3.a and b). The drifting longline and trawling fisheries also showed hotspots of activity in the South Atlantic Bight north of the Blake Spur, an area partly used by one bird in this study and by two birds in Jodice (2015). Additionally, the squid fishery, which targets a main prey of Black-capped Petrel, was limited to a small area southeast of the Dominican Republic (Figure D.3.d). No reports exist of Black-capped Petrel mortality from bycatch (Hata 2006, and Palka and Warden 2006, cited by Simons et al. 2013) and, because of its foraging behavior, the species is considered to be less susceptible to bycatch than larger pelagic species (Simons et al. 2013; Pearmain, BirdLife International, 2019, pers. com.). Nevertheless, it is important to note that recent studies of seabird bycatch in regional fisheries (Klaer 2012, Li et al. 2016) are data deficient in the Caribbean basin, especially in the southern Caribbean Sea. Moreover, most data available are limited to major commercial fleets and overlook the impact of local artisanal fisheries. The trawling fishery may also have an unquantified impact on the Black-capped Petrel: indeed, seabirds following trawling vessels and/or attracted to offal may lethally strike trawl and netsonde cables. These mortality events are often not reported by on-board bycatch observers since birds that are killed by cable strikes are not recovered (FAO 2009).

Explorative drilling and active oil and gas production are ongoing in the offshore waters of Colombia (two active wells are located ca. 11 and 17 km off the central Guajira Peninsula; Agencia Nacional de Hidrocarburos 2018) and Venezuela (one active well is located in the Gulf of Venezuela ca. 35 km west of the Paraguaná Peninsula; Offshore 2015). The Black-capped Petrel that foraged in the southern Caribbean Sea occurred in Colombian lease areas currently under evaluation, under exploration, or opened for concession (Table E.1 and Figure E.1, in Appendix E). The minimum distances to an active lease area and a well in production for the birds in this study were 83 km and 100 km, respectively (Tables E.1 and E.2). Black-capped Petrels tracked by Jodice et al. (2015) also foraged in lease areas off the coast of Colombia (Figure E.1) and the minimum distances to an active area and a well in production during that study were 7 km and 24 km, respectively (Tables E.1 and E.2). In addition, petrels tracked in 2014 occurred 34 km and 50 km from the active lease area and production well off the coast of Venezuela, respectively (Figure E.1). Furthermore, the individual in Jodice et al. (2015) that utilized the waters of the western Caribbean Sea and the Clark Basin also occurred in lease areas offshore of Colombia. Black-capped Petrels utilizing these areas for foraging and resting could potentially be

exposed to hydrocarbon releases during accidental oil spills and to increased concentrations of contaminants from uncontrolled seepage depending on the timing of such events.

While our study does not demonstrate that the Black-capped Petrel is subject to bycatch and/or mortality from oil and gas activities, our data do suggest that, at the macro-exposure scale, petrels are overlapping with fisheries and oil and gas activities. Exposure at the macro scale serves as a reasonable justification to encourage the collection of additional data to determine if petrels may be negatively impacted by these threats, as opposed to simply overlapping with their presence.

## 4.6 Implications for future research

*Tracking and At-sea Capture.* Numerous challenges must be overcome to further the study of movement patterns and spatial ecology of Black-capped Petrels. The remoteness and ruggedness of the species' breeding grounds, the location and depth of burrows, and limited periods of nest attendance during the chick-rearing phase complicate capture and subsequent tracking efforts. We demonstrated that remote-download GPS tags such as Mataki-LITE are viable to study petrel movements, provided adaptations in attachment location and recording settings are considered and further tested. Solar-powered satellite loggers deployed via a PTT have proved successful in the past (Jodice et al. 2015). Solar technology could alleviate issues with battery drainage as we experienced in this study but logging frequencies of solar-powered tracking devices currently available (e.g., 8 hours on, > 24 hours off) may limit their use for studies of fine-scale movements. The choice of a specific bio-logger will be a compromise among funding, tag size, and accessibility to birds.

To date, tracking data have focused on birds captured at breeding grounds. In contrast capturing birds at sea and tracking them back to breeding sites may reveal previously undescribed breeding locations. Our data indicate petrels may be rafting offshore of breeding sites and such locations (along with known foraging hot-spots) may provide opportunities for at-sea captures. Furthermore, locating consistent areas of petrel rafting could provide a means to further direct nest searching by suggesting consistent presence of birds in a region (Monteiro et al. 1999, Furness et al. 2000).

*Fisheries Interactions.* Our results also suggest that additional data are warranted with respect to the interactions of petrels and fishing activities. The at-sea range of the species is extensive, extending from the southern Caribbean Sea to waters offshore of the Canadian Maritime provinces (Simons et al 2013, Birdlife International 2018). Petrels are therefore exposed to a variety of fisheries that present a range of gear, potential entanglement, seasonality, competition, and perhaps supplementation of food. The collection of additional data using fine-scale GPS loggers would allow for an assessment of overlap with fishing activities to infer attraction and interaction. Data of a coarser resolution (i.e., from satellite tags) also could be used in model assessment or development. Lastly, the concurrent diet study led by the authors should update our knowledge of the species' diet during the breeding season and better inform our understanding of interactions between Black-capped Petrel and fisheries.

*Interactions with Energy and Telecommunications Infrastructure, and Urban Lighting.* Data from tracking studies can inform potential interactions with infrastructure (e.g., oil and gas, wind, and

telecommunications) both at-sea and on land. Tracking data have demonstrated exposure of petrels at the macro scale to oil and gas activities in the southern Caribbean Sea off Colombia and Venezuela. Additional data could allow for an assessment of exposure of petrels to lighting and flares at oil structures, and to contaminants associated with oil and gas exploration and production. Additional GPS data also can be used to determine if the recent construction of a wind farm at the eastern foothills of the Sierra de Bahoruco, Dominican Republic, overlapped with flight paths of petrels between nest sites and marine habitats. Local conservation organizations are also interested in determining if petrels use river valleys as flight paths. Many such valleys lead to or through urban setting with substantial levels of artificial light that could subsequently result in attraction and stranding of petrels (e.g., Telfer et al. 1987, Le Corre et al. 2002). Tracking data could therefore be used to conduct such a threat assessment, and additionally could provide focal areas for radar surveys.

*Individual-based Data from Handling and Captures.* In the process of tagging birds for tracking, additional data can be collected that can be used to inform gaps in our understanding of the species' physiology, ecology, and conservation. For example, because tracking studies require the handling of adults, long-term banding efforts can be initiated that in future years could inform our understanding of survival and nest-site fidelity. Many seabirds exhibit high fidelity to breeding and therefore an assessment of fidelity in petrels would contribute to conservation plans by providing detailed data on the consistency with which petrels may be exposed to natural and anthropogenic stressors at these sites or along commuting paths to these sites. Handling adults and chicks also provides opportunities to collect feathers and fecal matter. Feathers can be used to measure stable isotopes for diet assessment, and to measure baseline corticosterone for an assessment of stress and condition.

## **5 Concluding summary**

Our GPS tracking study of Black-capped Petrels from Sierra de Bahoruco, Dominican Republic, recorded the foraging movements of three chick-rearing adults during 8-11 day provisioning trips during April 2018. Tracked petrels travelled between 2,000 and 4,000 km and foraged 34.5% of the time they were away from nest sites. In two instances, at-sea behaviors were consistent with coastal rafting near confirmed and suspected breeding colonies. While our results showed differences in individual choices of foraging areas, they were similar to findings of Jodice et al. (2015) that demonstrated regular use of the Caribbean basin but infrequent use of the northwest Atlantic during the breeding season. Caution is warranted, however, given the small sample size of each study. For two of the birds in the current study, foraging areas appeared to be associated with physical processes such as the Guajira upwelling, and climatological fronts in the outer continental shelf of the South Atlantic Bight. Tracked petrels returned to the colony at night and one of them did so by following the general path of a river valley. While the tracking period was shorter than expected due to early battery drainage, the remote-download tracking technology used for this study can be improved and adapted for future tracking of the species, particularly when funding is limited. Implications for future research include more detailed assessments of threats at sea (e.g., interactions with fisheries and infrastructure for energy extraction) and on land (e.g., urban lighting and terrestrial wind farms near flight paths to and from colonies), and the

development and assessment of at-sea capture attempts which would allow tagged birds to be used to potentially locate unknown breeding locations.

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**Table 1. Physical, biological and human oceanographic datasets assessed for a preliminary analysis of the marine habitat and threats influencing Black-capped Petrels during chick rearing at Sierra de Bahoruco, Dominican Republic, 20 April to 1 May 2018.**

Variable	Dataset	Temporal resolution	Spatial resolution	Units	Sampling period
Bathymetry	ETOPO1 (etopo180)	-	0.016°	m	na
Sea surface temperature	MUR SST (jplMURSST41mday)	Monthly	0.01°	°C	April 2018
Sea surface temperature gradient	NOAA NESDIS COASTWATCH (CW_BLENDED_NIGHT_SST)	Monthly	4 km	°C	April 2018
Sea level anomaly	NOAA NESDIS (noaa_nesdis_star_SLA)	Daily	0.25°	m	25 April 2018
Fishing effort	Global Fish Watch 2012-2016	-	4 km	h/km <sup>2</sup>	2012-2016
Hydrocarbon lease areas	Colombia: ANH 2018 Venezuela: NOAA EOG 2018	-	-	-	1958-2017 April 2018

**Table 2. Morphometrics, nest status, and color phase of twelve Black-capped Petrels captured at Sierra de Bahoruco, Dominican Republic, 15 to 21 April 2018. na = not applicable.**

Band numbers in bold indicates that birds were caught in the same burrow.

GPS ID.	Base ID.	Band	Capture date	Mass (g)	Wing cord length (mm)	Tarsus length (mm)	Culmen length (mm)	Gonys depth (mm)	Color phase <sup>a</sup>	Face pattern <sup>b</sup>	Handling time (min)
na	na	1343-78601	15 April	370	na	39.35	32.15	13.65	3.0	f	13
101	201	1343-78602	17 April	385	na	39.55	30.70	13.15	2.0	e-f	16
102	201	1343-78603	17 April	450	na	40.65	33.15	14.35	2.0	e-f	10
103	201	1343-78604	17 April	415	na	40.30	32.31	12.90	1.5	e	9
na	Ns	1343-78605	18 April	345	na	39.15	30.90	13.10	2.0	e-f	15
104	201	1343-78606	19 April	435	301	39.90	32.30	12.10	3.0	f	14
107	202	1343-78607	19 April	385	303	37.80	31.50	12.70	3.0	f	9
na	na	1343-78608	19 April	360	298	39.10	33.00	13.55	3.0	f	8
108	203	1343-78611	19 April	395	299	39.50	31.25	12.95	1.5	e	10
109	203	<b>1343-78616</b>	20 April	405	296	39.50	32.55	13.60	0.0	d	9
110	203	<b>1343-78615</b>	20 April	410	298	37.90	33.40	13.15	1.5	e	8
111	203	1343-78612	21 April	430	302	40.75	32.00	13.45	1.5	e	10
			<i>mean</i>	<i>399</i>	<i>300</i>	<i>39.45</i>	<i>32.10</i>	<i>13.22</i>			
			<i>sd</i>	<i>31.6</i>	<i>2.5</i>	<i>0.93</i>	<i>0.87</i>	<i>0.56</i>			
			<i>min</i>	<i>345</i>	<i>296</i>	<i>37.80</i>	<i>37.80</i>	<i>12.10</i>			
			<i>max</i>	<i>450</i>	<i>303</i>	<i>40.75</i>	<i>40.75</i>	<i>14.35</i>			

<sup>a</sup> Scale based on Lamoreaux (2013)

<sup>b</sup> Scale from Howell and Patteson (2008)

**Table 3. Comparison of morphometrics of Black-capped Petrels captured at Sierra de Bahoruco, Dominican Republic in 2014 and 2018 and captured in the same burrows.**

Nest	GPS/PTT ID.	Band	Capture year <sup>a</sup>	Mass (g)	Wing cord length (mm)	Tarsus length (mm)	Culmen length (mm)	Gonys depth (mm)	Color phase	Face pattern
A	109	1343-78616	2018	405	296	39.50	32.55	13.60	0.0	d
	110	1343-78615	2018	410	298	37.90	33.40	13.15	1.5	e
B	107	1343-78607	2018	385	303	37.80	31.50	12.70	3.0	f
	176	1633-02638	2014	425	291	38.20	32.50	13.40	3.0	f

<sup>a</sup> 2014: Jodice et al (2015); 2018: this study.

**Table 4. Summary of morphometric measurements of Black-capped Petrels, 1980-2018**

Study	Sex	Mass (g)						Wing cord (mm)						Wing length (mm)					
		mean	sd	min	max	cv	n	mean	sd	min	max	cv	n	mean	sd	min	max	cv	n
Monograph <sup>1</sup>	-	437.7	56.1	347.0	557.2	0.13	59	288.4	16.56	247	308	0.06	13	399.8	15.80	375	437	0.04	57
	f	425.9	53.13	347.0	545.4	0.12	17	291.5	10.93	280	305	0.04	6	398.9	15.17	375	432	0.04	17
	m	442.5	57.17	348.9	557.2	0.13	42	285.7	20.76	247	308	0.07	7	400.2	16.24	378	437	0.04	40
2014 <sup>2</sup>	u	382.5	37.75	335.0	425.0	0.10	4	292.2	1.50	291	294	0.01	4						
2018 <sup>3</sup>	u	398.8	31.56	345.0	450.0	0.08	12	299.6	2.51	296	303	0.01	7						

Study	Sex	Culmen length (mm)						Culmen depth <sup>a</sup> (mm)						Tarsus (mm)					
		mean	sd	min	max	cv	n	mean	sd	min	max	cv	n	mean	sd	min	max	cv	n
Monograph <sup>1</sup>	-	33.3	1.75	29.2	38.6	0.05	50	15.5	1.07	13.0	18	0.07	50						
	f	32.6	1.61	29.2	35.0	0.05	15	14.9	0.84	13.7	17	0.06	15						
	m	33.6	1.73	31.2	38.6	0.05	35	15.8	1.06	13.0	18	0.07	35						
2014 <sup>2</sup>	u	32.0	1.12	30.5	33.1	0.03	4	13.2	0.37	12.8	14	0.03	4	39.4	0.84	38.2	40	0.02	4
2018 <sup>3</sup>	u	32.1	0.87	30.7	33.4	0.03	12	13.2	0.56	12.1	14	0.04	12	39.5	0.93	37.8	41	0.02	12

<sup>1</sup> Adults and immatures captured in the Gulf Stream (from data summarized in Simons et al 2013)

<sup>2</sup> Breeding adults captured at Loma del Toro, Dominican Republic (Jodice et al 2015)

<sup>3</sup> Breeding adults captured at Loma del Toro, Dominican Republic (this study)

<sup>a</sup> Location of measurement was not indicated in Simons et al (2013). For 2014 and 2018, culmen depth was measured at gonys.

**Table 5. Results of unpaired two-sample t-tests of morphometric variables (unequal variances).**

Wing cord and wing length were not tested as measurements can vary greatly due to feather conditions and observer experience. *t*: t-value; *df*: degree of freedom; *p*: p-value. Values in bold are considered significant results at  $\alpha = 0.05$ . Values in parentheses are considered unreliable due to possible differences in measurement methods.

Tested samples	Mass			Culmen length <sup>a</sup>			Culmen depth <sup>b</sup>			Tarsus		
	<i>t</i>	<i>df</i>	<i>p</i>	<i>t</i>	<i>df</i>	<i>p</i>	<i>t</i>	<i>df</i>	<i>p</i>	<i>t</i>	<i>df</i>	<i>p</i>
Monograph (breed. time) <sup>1</sup> vs Monograph (non-breed. time) <sup>2</sup>	<b>3.65</b>	<b>55.35</b>	<b>&lt;0.005</b>	0.17	39.59	0.86	0.15	44.12	0.87			
Monograph (female) <sup>3</sup> vs Monograph (male) <sup>4</sup>	1.06	31.79	0.29	1.16	19.27	0.25	<b>3.02</b>	<b>33.28</b>	<b>0.005</b>			
2014 <sup>5</sup> vs 2018 <sup>6</sup>	0.77	4.49	0.47	0.21	4.30	0.85	0.09	8.24	0.93	0.11	5.69	0.92
Monograph <sup>7</sup> vs Loma del Toro <sup>8</sup>	<b>3.92</b>	<b>41.66</b>	<b>&lt;0.005</b>	<b>2.98</b>	<b>35.84</b>	<b>0.005</b>	<b>(11.77)</b>	<b>(54.11)</b>	<b>(&lt;0.005)</b>			
Monograph (breed. time) <sup>1</sup> vs Loma del Toro <sup>8</sup>	1.36	41.64	0.18	<b>2.40</b>	<b>35.57</b>	<b>0.02</b>	<b>(8.54)</b>	<b>(33.43)</b>	<b>(&lt;0.005)</b>			

<sup>1</sup> Samples in Simons et al (2013) that were collected during the breeding season (March-August)

<sup>2</sup> Samples in Simons et al (2013) that were collected outside the breeding season (September-February)

<sup>3</sup> Samples from female individuals in Simons et al (2013)

<sup>4</sup> Samples from male individuals in Simons et al (2013)

<sup>5</sup> Breeding adults captured at Loma del Toro, Dominican Republic (Jodice et al 2015)

<sup>6</sup> Breeding adults captured at Loma del Toro, Dominican Republic (this study)

<sup>7</sup> All samples in Simons et al (2013)

<sup>8</sup> Grouping of samples from 2014 and 2018.

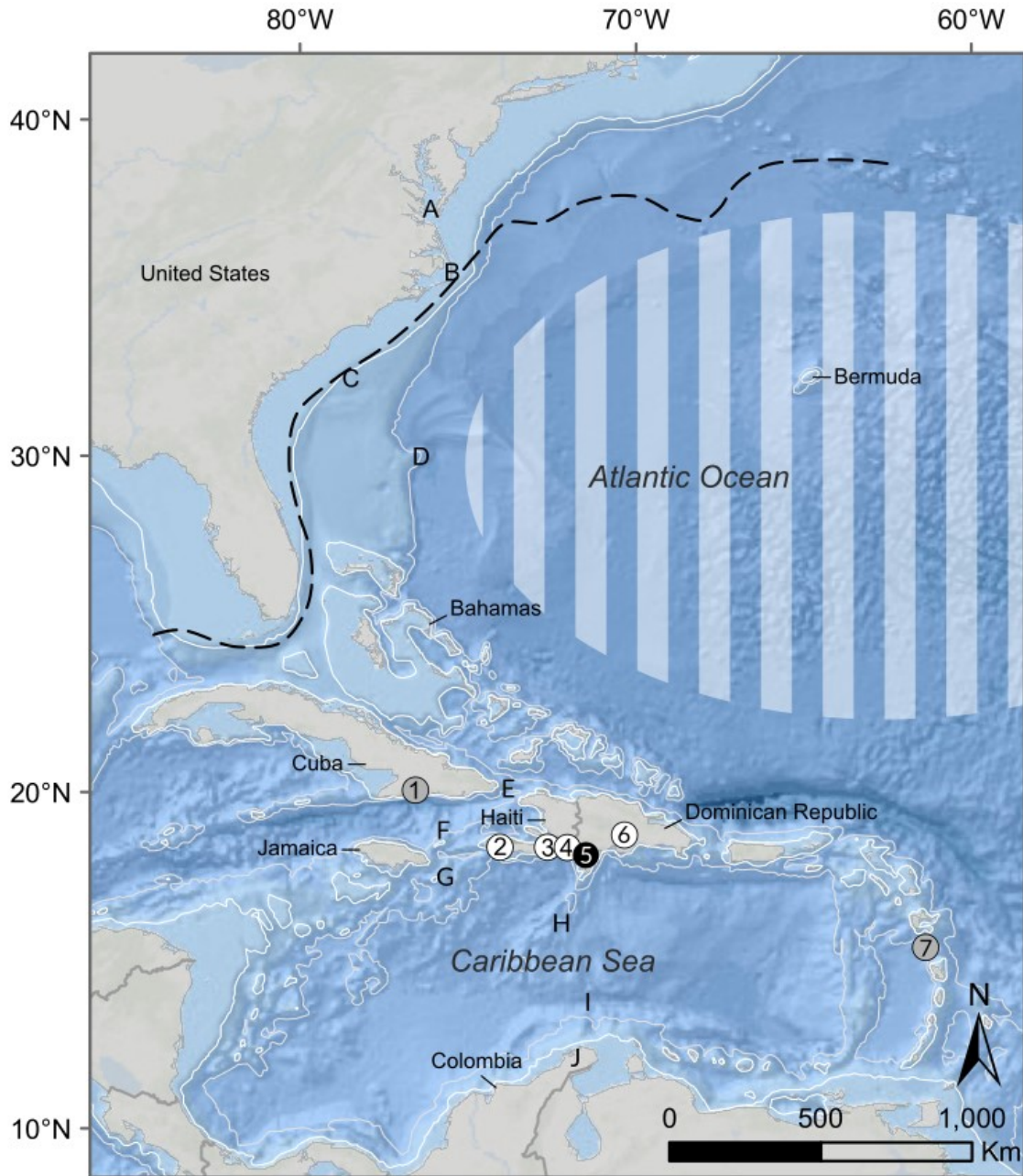
<sup>a</sup> Four outliers with culmen lengths >36.0 mm (Monograph) were removed from the analysis

<sup>b</sup> a Location of measurement was not indicated in Simons et al (2013). For 2014 and 2018, culmen depth was measured at gonys

**Table 6. Characteristics of trips made by GPS-tracked Black-capped Petrels during chick rearing at Sierra de Bahoruco, Dominican Republic, 20 April to 1 May 2018.**

Trip start and end dates were estimated based on GPS data and communication to base-stations. Due to the temporal resolution of the data, Total trip distance corresponds to the minimum distance effectively covered by the bird. Capital letters used in describing destinations refer to oceanographic features listed in Figure 1.

Bird ID.	No. of locations	Trip duration (d)	Total trip distance (km)	Maximum distance from colony (km)	Max speed (km/h)	Dates and destinations
107	159	8	2,057	445	46	20 – 28 April; Beata Ridge (H) and Jamaica Channel
110	96	10	2,756	765	39	21 – 30 April; Aruba Gap (I) and offshore Columbia
111	99	11	4,651	1,503	49	21 April – 1 May; Offshore Cuba to Windward Passage (E) to western Sargasso Sea.



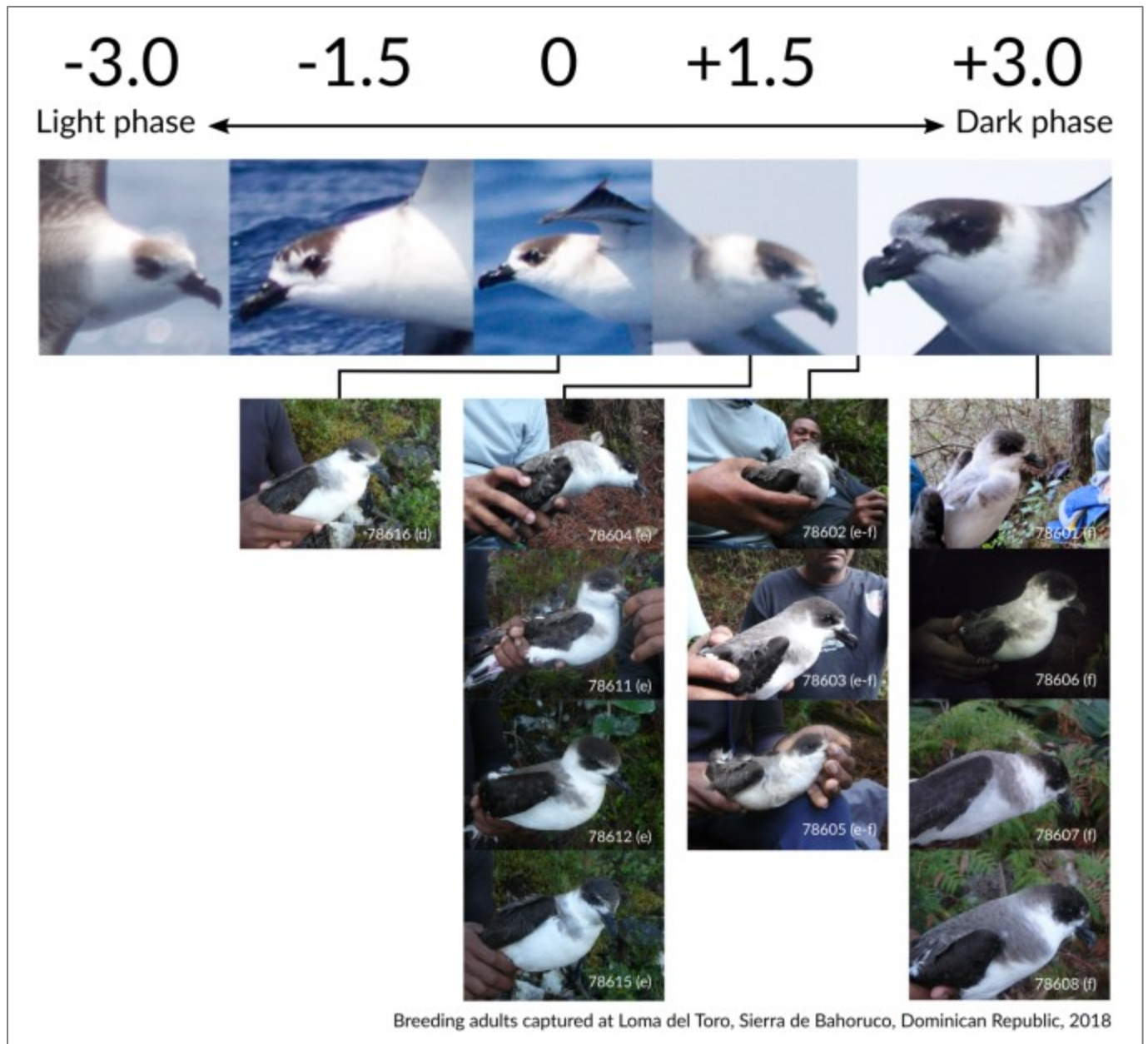
**Figure 1. Map of study area (adapted from Jodice et al 2015).**

Circles with numbers indicate breeding colonies of Black-capped Petrel (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; 6: Valle Nuevo, Dominican Republic; 7: Dominica.

Letters indicate geographic and oceanographic features. A: Chesapeake Bay; B: Cape Hatteras; C: Charleston Bump; D: Blake Spur; E: Windward Passage; F: Formigas Bank; G: Albatross Bank; H: Beata Ridge; I: Aruba Gap; J: Guajira Peninsula. Dashed line estimates the western edge of the Gulf Stream for April 2018. Dashed area indicates the approximate location of the Sargasso Sea. Solid lines indicate bathymetry: 200 m (white) and 2000 m (grey).



**Figure 2. Typical nesting habitat of Black-capped Petrel in Loma del Toro, Sierra de Bahoruco, Dominican Republic.**

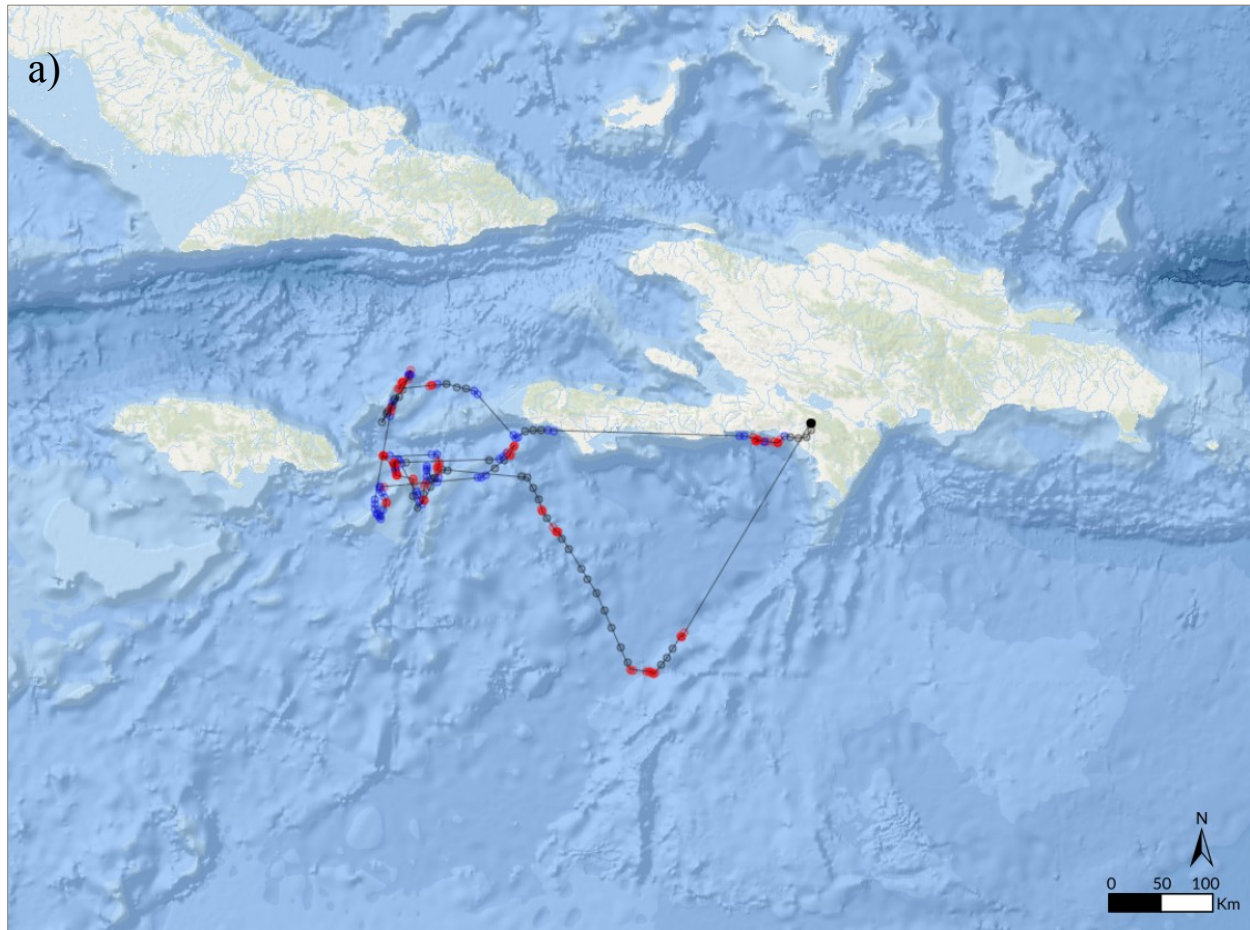


**Figure 3. Color phases of Black-capped Petrels captured at Sierra de Bahoruco, Dominican Republic, 15 to 21 April 2018.**  
 Numerical scale adapted from Lamoreaux (2013). Letters in parentheses refer to the discrete scale proposed by Howell and Patterson (2008).



**Figure 4. Movements of GPS-tracked Black-capped Petrels during chick rearing at Sierra de Bahoruco, Dominican Republic, 20 April to 1 May 2018.**

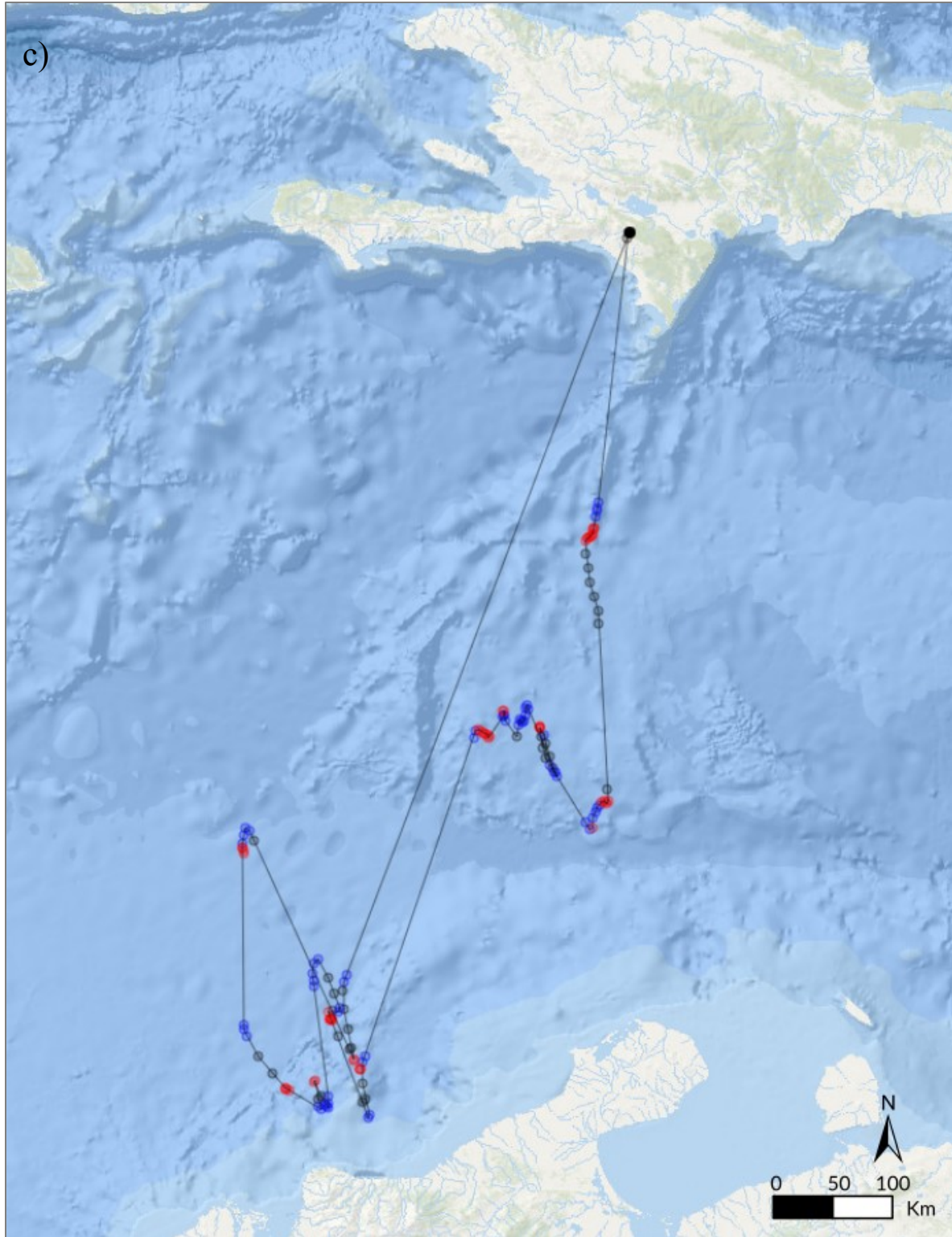
Black circle indicates breeding colony. Locations are color-coded by RST behavior: grey = transit, red = rest, blue = foraging.



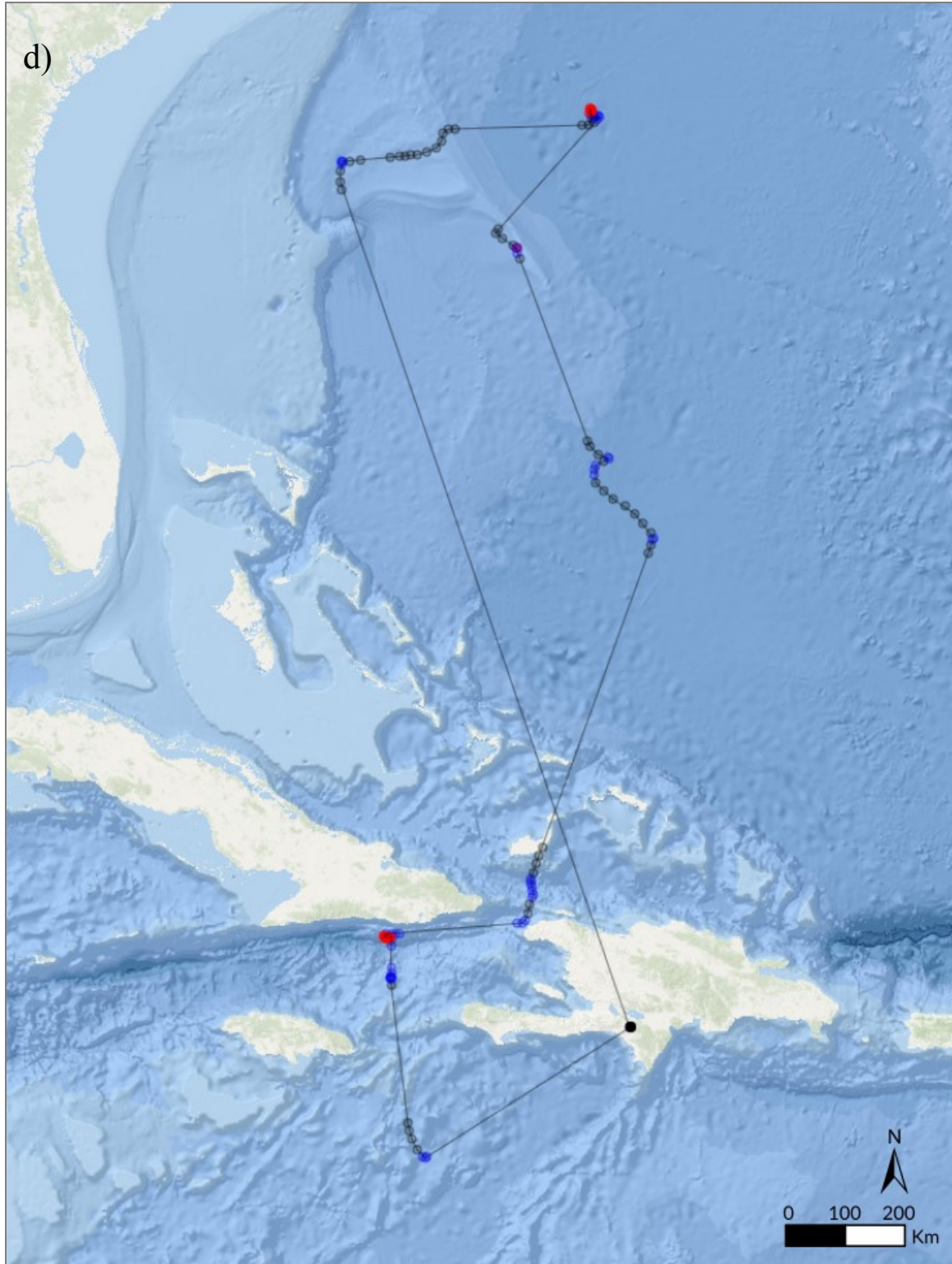
(a) Bird 107 (1343-78607): 20 – 29 April.



(b) Bird 107 (1343-78607): 28 April: blue circle indicates colony, red circles indicate Anse à Cochon and Boucan Guillaume, Haiti



(c) Bird 110 (1343-78615): 21 – 30 April.



(d) Bird 111 (1343-78612): 21 April – 1 May.

## Appendix A: GPS logging script used to track Black-capped Petrels with GPS technology

All scripts were written in BASIC language and adapted for this study.

```
10 REM =====
20 REM === This is an example script for Mataki-Lite ===
30 REM === Copyright Debug Innovations Ltd. 2018 ===
40 REM === V1.4 26 February 2018 ===
45 REM === Adapted by Y.G. Satge 2018 ===
50 REM =====
60 PRINT
70 PRINT "Mataki-Lite Tracker Script V1.4"
80 PRINT "Copyright Debug Innovations Ltd. 2017-2018"
90 PRINT "BCPE Version 2.3.3"
91 PRINT
92 PRINT COLOR(2); "GPS_ID = "; _ID ; COLOR(0)
93 PRINT COLOR(2); "_FREQBASE = "; _FREQBASE ; COLOR(0)
94 PRINT
100 REM *** GPS Tracking Settings ***
110 fixnormal = 30 * 60 : REM When battery is good
115 fixlowbatt = 180 * 60 : REM When battery is low
116 fixinterval = fixnormal
120 firstfixsearchtime = 4 * 60 : REM Leave GPS on for max. 4 mins to get first fix
130 fixsearchtime = 50 : REM Leave GPS on for max. 50 secs to get subsequent fixes
140 gpsmode = 1 : REM Automatic mode: Get a fix and log it
150 PRINT "GPS fix interval: "; fixinterval / 60 ; " minutes"
160 REM *** Radio Settings ***
170 radiointerval = 10 * 60 : REM When battery is good
171 radiointerval_near = 2 * 60 : REM When bird is in nearest geofence
177 PRINT "Base Radio interval : "; radiointerval / 60 ; " minutes"
179 PRINT "Initial battery voltage : "; _Vbatt ; "V"
180 PRINT
181 REM *** GEOFENCE Settings ***
182 baselat = 18.28
183 baselon = -71.71
184 buffer_distance = 150 * 1000 : REM Geofence distance in km (m*1000)
185 buffer_distance_nearest = 25 * 1000 : REM Nearest geofence for shorter radio contact
186 PRINT COLOR(6); "Base location: "; baselat; ", "; baselon; COLOR(0)
187 REM lastfix_lat/lon are updated when GPS gets fix; if no fix (lastfix_lat = 0): geofence sends tag back to sleep
188 lastfix_lat = 0
189 lastfix_lon = 0
199 REM *** Startup state ***
200 _LED = 0
210 _GPS = 0
220 fixes = 0
221 t = CLOCK
230 fixtime = CLOCK + fixinterval
240 radiotime = CLOCK + radiointerval
250 sleeptime = 60
260 radioled = 1
270 REM *** Main Loop ***
300 PRINT "Hello"
305 IF CLOCK >= fixtime THEN PRINT "GPS loop": GOSUB 1000
310 IF (CLOCK >= radiotime) GOTO 2500
320 REM *** Enter low power mode for a maximum of <sleeptime> seconds ***
330 PRINT "***SLEEP***" : _SLEEP = sleeptime
360 GOTO 300
```

```

999 REM *** Try to get a GPS Fix ****
1000 PRINT TIME$;" GPS On"
1020 IF fixes = 0 GOSUB 1200 ELSE GOSUB 1400
1100 _GPS = 0
1110 IF _FIXVALID = 0 THEN 1120
1112 PRINT "Lat:"; _FIXLAT ;" Long:"; _FIXLON ;" Alt:"; _FIXALT ;" HDOP:"; _FIXHDOP;" SATS:"; _FIXSATS
1113 IF _FIXLAT <> 0 THEN lastfix_lat = _FIXLAT
1114 IF _FIXLON <> 0 THEN lastfix_lon = _FIXLON
1115 GOSUB 6000
1116 fixes = fixes + 1
1118 PRINT fixes ;" fixes"
1120 PRINT TIME$;" GPS Off"
1130 PRINT "Log Used = "; _logused ;"/"; _logcap ;" entries ("; ROUND((_logused * 100) / _logcap) ;"%)"
1140 PRINT "Battery "; _Vbatt ;"V"
1145 IF (_Vbatt < 3.5) fixinterval = fixlowbatt
1150 PRINT TIME$;" Next fix in "; fixinterval / 60 ;" minutes"
1160 fixtime = CLOCK + fixinterval
1190 RETURN
1199 REM *** First Fix - CLOCK value will jump when GPS time is set ***
1200 endtime = CLOCK + firstfixsearchtime
1210 REPEAT
1220 t1 = CLOCK
1230 _GPS = gpsmode
1240 t2 = CLOCK
1250 IF (t2 - t1) < 10 THEN GOTO 1300
1260 REM GPS Time has reset CLOCK - update all the timer values depending on it
1270 endtime = t2 + (endtime - t1)
1280 fixtime = t2 + (fixtime - t1)
1290 radiotime = t2 + (radiotime - t1)
1300 UNTIL _FIXVALID OR (CLOCK > endtime)
1310 RETURN
1399 REM *** Normal Fix - We should be able to rely on CLOCK value now ***
1400 endtime = CLOCK + fixsearchtime
1410 REPEAT
1430 _GPS = gpsmode
1460 UNTIL _FIXVALID OR (CLOCK > endtime)
1500 RETURN
1999 REM *** Radio ****
2000 IF _LOGUSED = 0 THEN PRINT "No logs to send to base station" : GOTO 2100
2010 PRINT COLOR(6); "Radio loop: Trying to contact base station"; COLOR(0)
2020 _RADIO = 1
2025 d = 1
2030 REM Wait with the radio on until we timeout
2035 REM If contact is made with the base-station, the tag will upload its log and perform a reset when the upload is finished,
thus de-facto ending the loop
2040 REPEAT
2050 DELAY 0.01
2060 IF (d MOD 200) = 0 THEN _LED = radioled
2070 IF (d MOD 200) = 5 THEN _LED = 0
2080 d = d + 1
2085 UNTIL _CONTACT = 0
2086 REM Either no contact or the radio transaction was incomplete
2090 _RADIO = 0
2100 _LED = 0
2110 PRINT TIME$;" Next radio in "; radiointerval / 60 ;" minutes"
2150 radiotime = CLOCK + radiointerval
2190 GOTO 330
2499 REM Checking Geofence

```

```

2500 IF (_Vbatt < 3.5) GOTO 2000
2505 PRINT COLOR(6); TIME$; " Checking GEOFENCE"; COLOR(0)
2510 REM If no fix since startup (lastfix_lat = 0): geofence sends tag back to sleep
2515 IF lastfix_lat = 0 THEN PRINT "No fix since startup" : GOTO 2110
3005 IF (distance < buffer_distance_nearest) radiointerval = radiointerval_near : GOTO 2000
3006 IF (distance < buffer_distance) PRINT COLOR(2); TIME$; " Inside geofence"; COLOR(0) : GOTO 2000
3007 PRINT COLOR(1); TIME$; " Outside geofence"; COLOR(0)
3020 GOTO 2110
5997 REM *** Calculate distance between 2 locations ***
5999 REM The result will be in distance variable (meters)
6000 latarc = (lastfix_lat - baselat) * _DEGTORAD
6010 lonarc = (lastfix_lon - baselon) * _DEGTORAD
6020 lath = SQ(SIN(latarc * 0.5))
6030 lonh = SQ(SIN(lonarc * 0.5))
6040 cospart = COS(lastfix_lat * _DEGTORAD) * COS(baselat * _DEGTORAD)
6050 sinx = SQR(lath + (cospart * lonh))
6060 sinxx = SQR((0 - sinx) * sinx + 1)
6070 IF sinxx = 0 THEN arcrad = _PI ELSE arcrad = 2 * ATN(sinx / sinxx)
6080 distance = arcrad * _EARTHMR
6090 PRINT COLOR(6); "Distance to Base = "; distance/1000; "km"; COLOR(0)
6100 RETURN

```

## Appendix B: Management of power consumption in GPS loggers used to track Black-capped Petrels

We wrote the logging script to optimize power consumption by the GPS logger in two ways. First, we created two geofences (of respective 25 km and 150 km radius from the colony) to control the frequency of UHF communication “heartbeats”: a heartbeat was sent every 2 minutes when inside the 25 km geofence (based on the coordinates of the last recorded GPS location), every 10 minutes when inside the 150 km geofence, and no heartbeat was sent when more than 150 km away from the colony (Table B.1). Then, when the battery power decreased below a threshold of 3.5 V, a simple “low voltage” loop reduced the GPS logging schedule from every 30 minutes to every 180 minutes, and the frequency of UHF heartbeats was scheduled to every 10 minutes disregarding of the distance to the colony. Stationary tests were performed before deployment to debug the script and estimate battery life.

**Table B. 1. Summary of GPS and radio communication schedules used to track Black-capped Petrels captured at Sierra de Bahoruco, Dominican Republic, 15 and 21 April 2018.**

		Outside geofence ( $\geq 150\text{km}$ )	Inside wide geofence ( $< 150\text{km}$ )	Inside near geofence ( $< 25\text{km}$ )
Normal voltage ( $\geq 3.5\text{v}$ )	GPS schedule	30 min	30 min	30 min
	Radio check	10 min	10 min	2 min
	Radio communication	NA	10 min	2 min
Low voltage ( $< 3.5\text{v}$ )	GPS schedule	180 min	180 min	180 min
	Radio check	10 min	10 min	10 min
	Radio communication	10 min	10 min	10 min

**Table B. 2. Voltage at time of data upload from GPS loggers used to track Black-capped Petrels captured at Sierra de Bahoruco, Dominican Republic, 15 and 21 April 2018.**

GPS ID.	Upload timestamp	Voltage (v)
107	2018-04-29 02:11:02	3.52
110	2018-05-01 02:41:11	3.30
111	2018-05-02 02:59:57	3.29



## Appendix C: Details on field deployments of base-stations used to track Black-capped Petrels with GPS technology

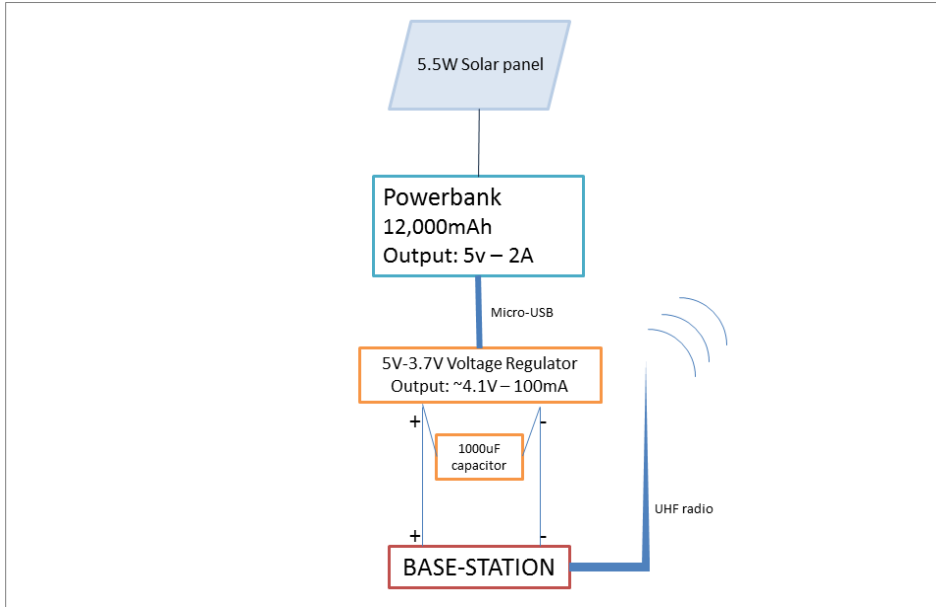


Figure C.1. Diagram of base-stations deployment at Sierra de Bahoruco, Dominican Republic, April 15 to 2 June 2018.

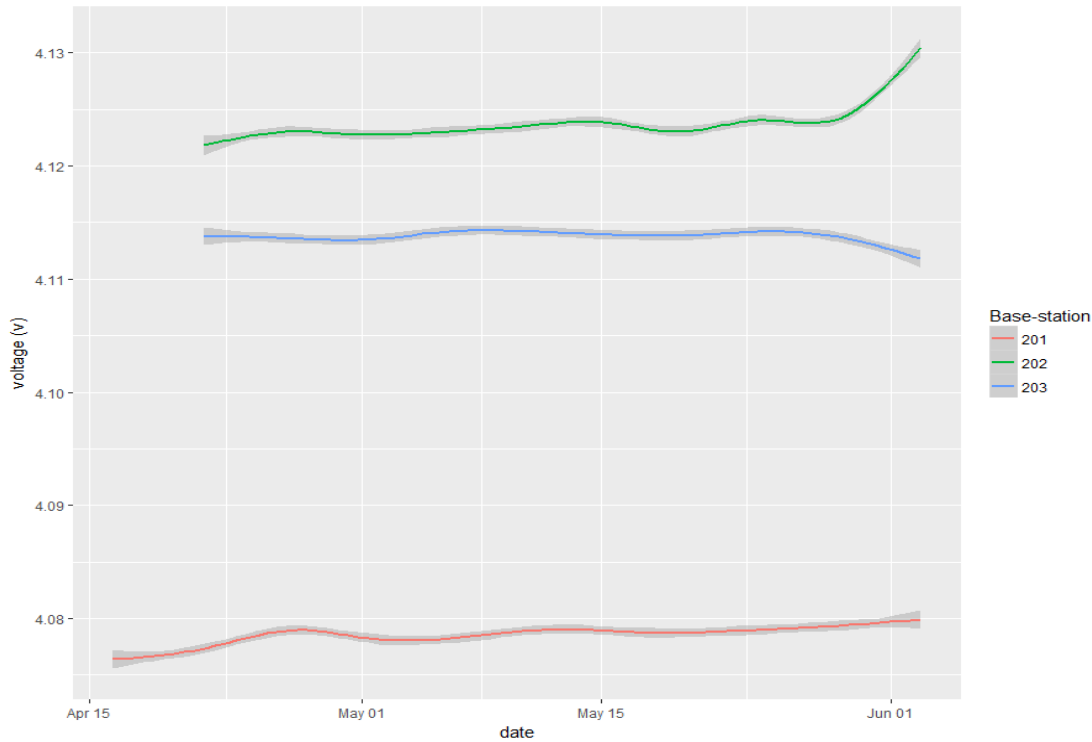
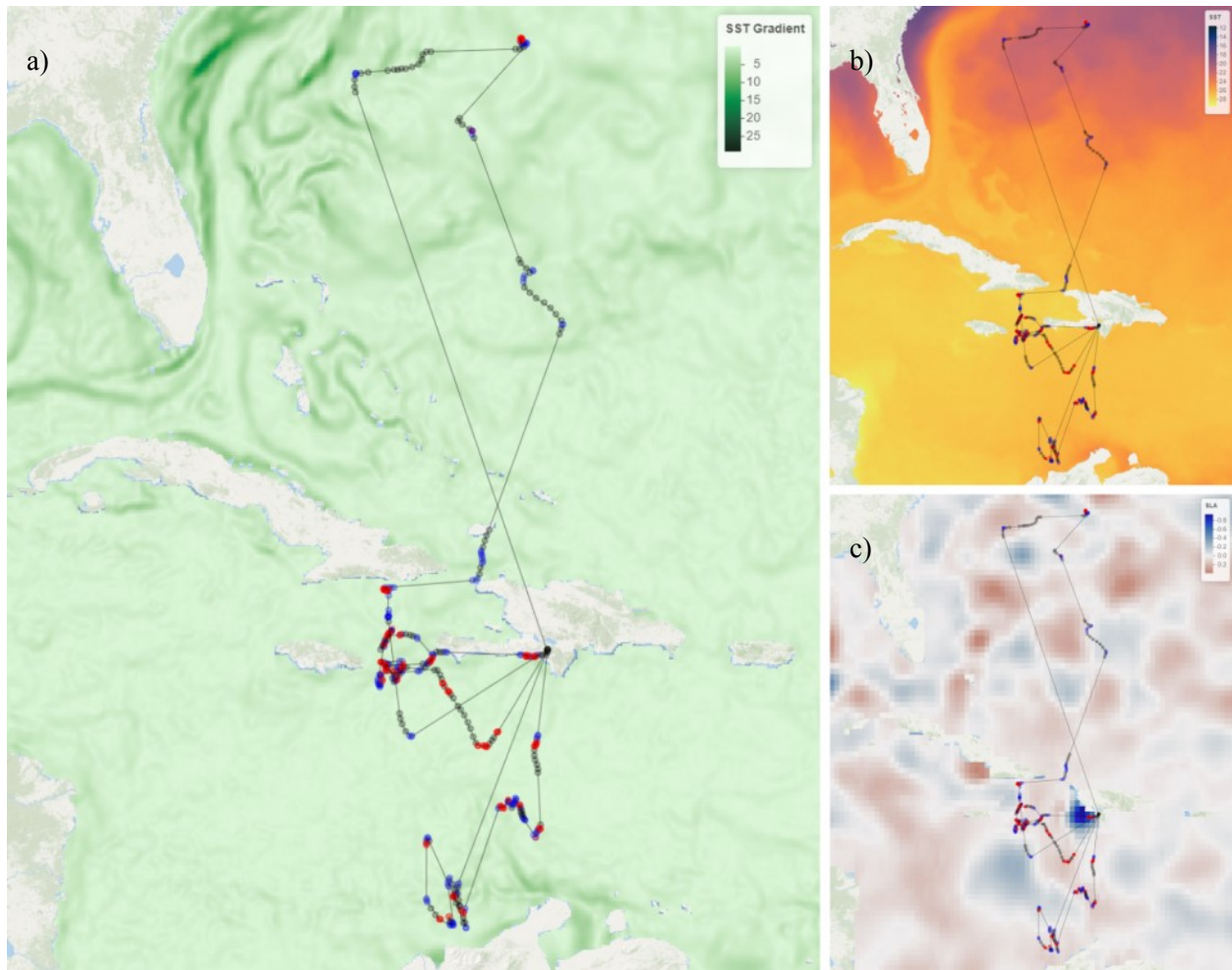


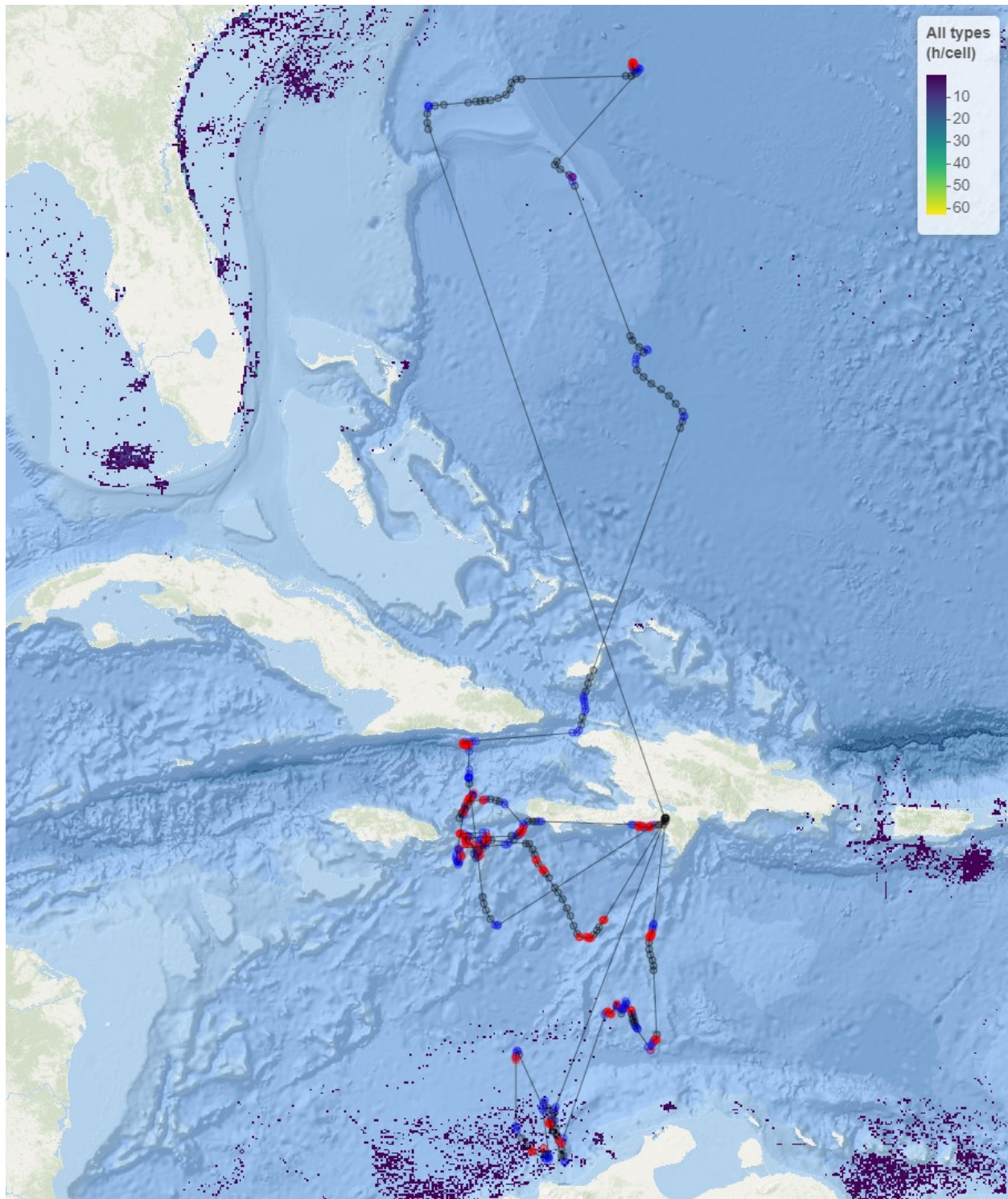
Figure C.2. Voltage levels recorded during the deployment of base-stations at Sierra de Bahoruco, Dominican Republic, April 15 to 2 June 2018.

## Appendix D: Exploration of correlations between oceanographic data and movement of Black-capped Petrels



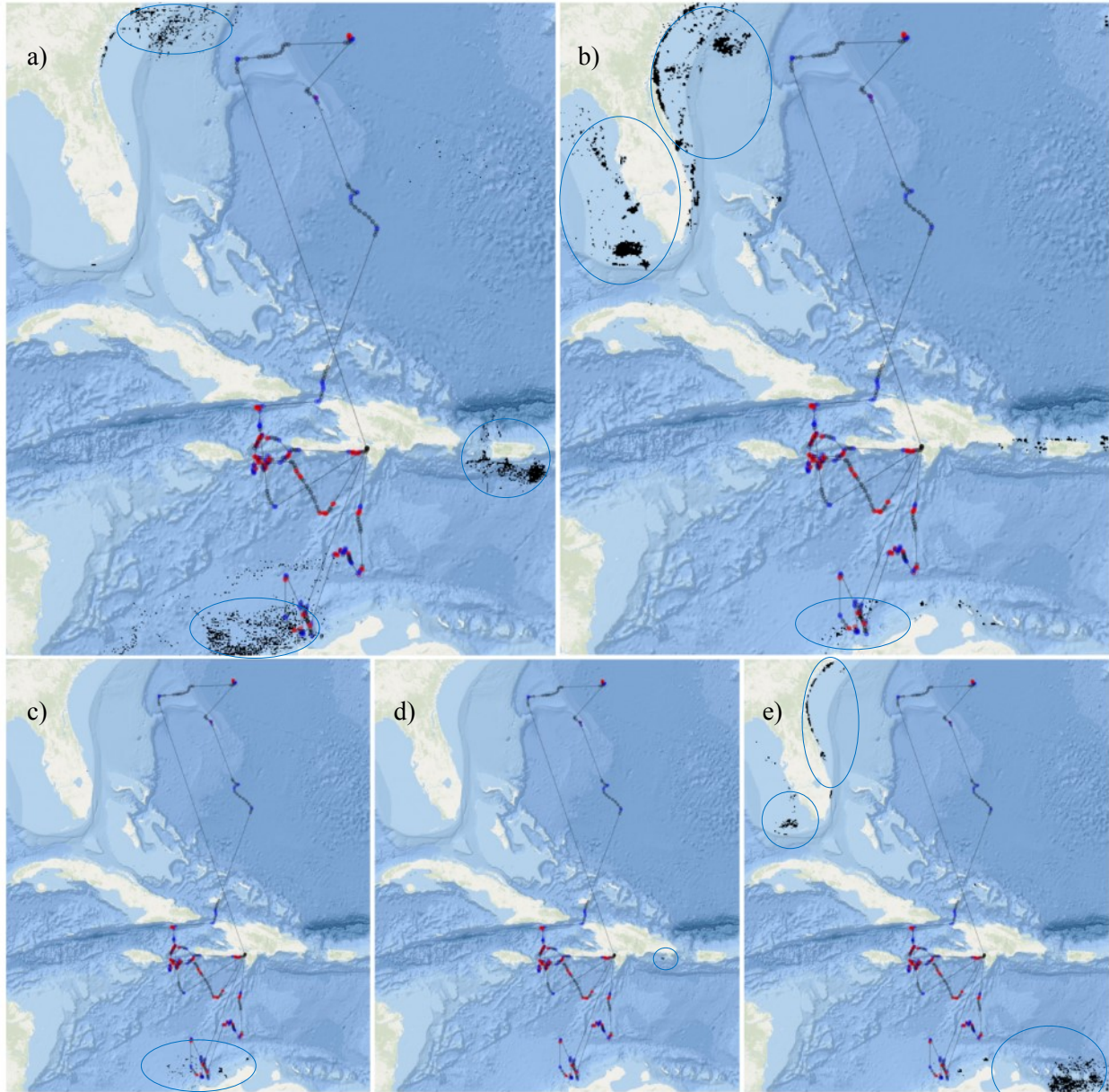
**Figure D.1. . Movements of GPS-tracked Black-capped Petrels during chick rearing at Sierra de Bahoruco, Dominican Republic, 20 April to 1 May 2018.**

Location data are overlaid on (a) sea surface temperature gradient, (b) sea surface temperature, and (c) sea level anomaly. In (a), color scale goes from light (weak temperature gradient) to dark strong gradient); in (b), color scale goes from purple (lower temperatures) to yellow (higher temperatures); in (c), color scale goes from blue (negative anomaly) to red (positive anomaly) with mean sea level height in white. Petrel locations are color-coded by RST behavior: grey = transit, red = rest, blue = foraging.



**Figure D.2. Movements of GPS-tracked Black-capped Petrels during chick rearing at Sierra de Bahoruco, Dominican Republic, 20 April to 1 May 2018.**

Location data are overlaid on dataset of total fishing effort (in fishing hours per cell), 2012-2016. Source: Global Fishing Watch (2018).



**Figure D.3. Movements of GPS-tracked Black-capped Petrels during chick rearing at Sierra de Bahoruco, Dominican Republic, 20 April to 1 May 2018.**

Location data are overlaid on fishing footprint by type of gear (2002-2016): (a) drifting longline, (b) trawler, (c) fixed gear (including set longlines and set gillnets), (d) squid jigger, and (e) other (troller, pole and line and unknown gear). Blue ovals locate core use areas by gear. Petrel locations are color-coded by RST behavior: grey = transit, red = rest, blue = foraging. Source: Global Fishing Watch (2018).

## Appendix E: Exploration of Black-capped Petrel exposure to oil and gas activities in the southern Caribbean Sea

**Table E.1. Distance between Black-capped Petrel locations and oil and gas lease in the Southern Caribbean Sea, 2014 and 2018.**

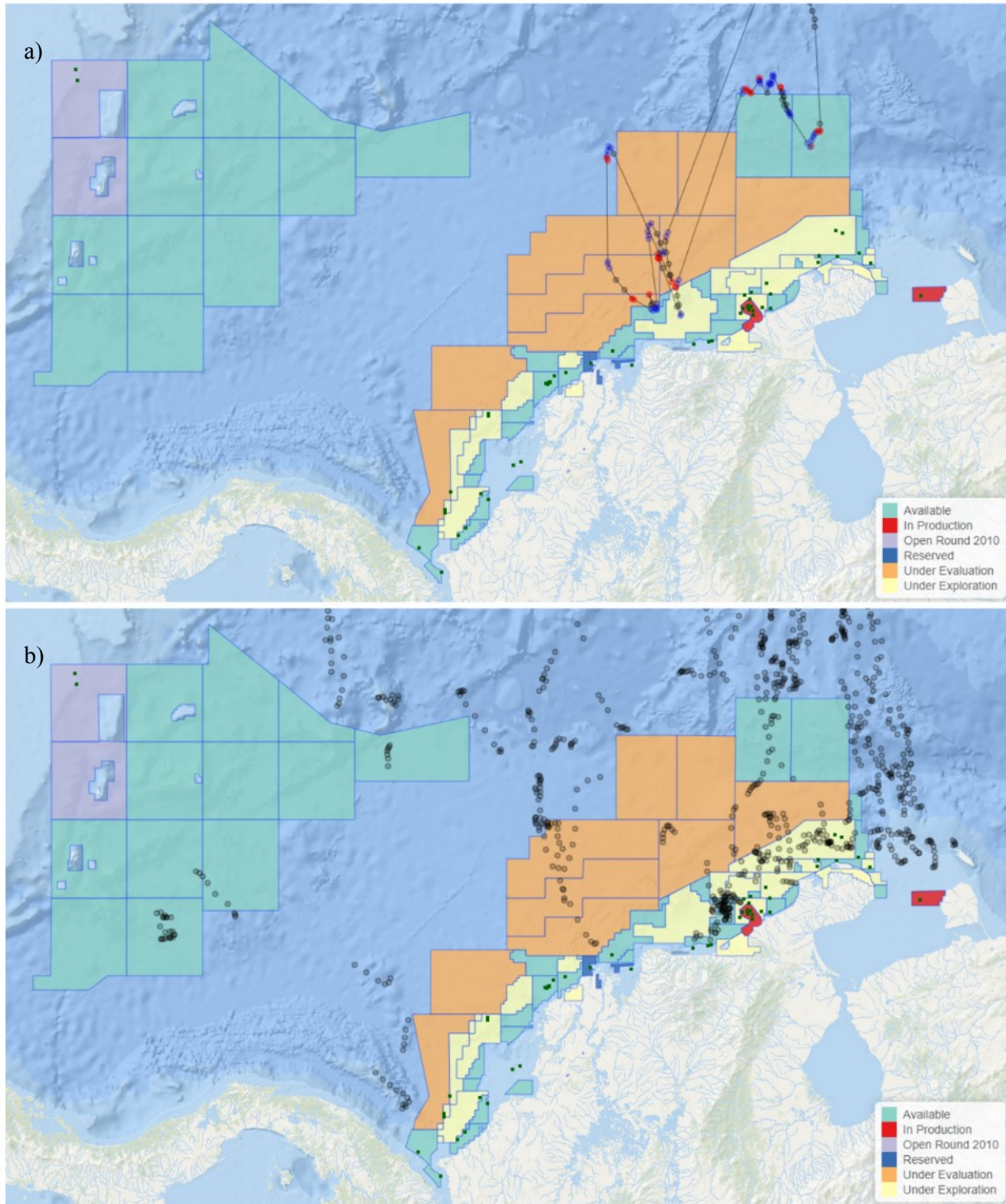
n = number of tracking locations within distance to lease area. To ease reading, bins with 0 locations have been left blank.

Distance (km)	Lease type							
	In Production (n)		Available (n)		Under Exploration (n)		Under Evaluation (n)	
	2014	2018	2014	2018	2014	2018	2014	2018
0-20	21		234	75	186	21	142	62
20-50	71		174	13	51	17	142	7
50-100	89	11	231	24	116	21	207	51

**Table E.2. Distance between Black-capped Petrel locations and oil and gas infrastructures in the Southern Caribbean Sea, 2014 and 2018.**

n = number of tracking locations within distance to infrastructure. To ease reading, bins with 0 locations have been left blank.

Distance (km)	Extraction status					
	In Production (n)		Exploratory (n)		Abandoned (n)	
	2014	2018	2014	2018	2014	2018
0-20			11		13	
20-50	59		47		136	
50-100	66	1	164		99	23



**Figure E.1. Black-capped Petrel locations during chick rearing at Sierra de Bahoruco, Dominican Republic, overlaid on oil and gas lease areas (shaded polygons) and infrastructure locations (green squares) in the Southern Caribbean Sea (a) 20 April to 1 May 2018, and (b) 8 April to 30 June 2014.**

2018 petrel locations are color-coded by RST behavior: grey = transit, red = rest, blue = foraging. Source: Colombia: Agencia Nacional de Hidrocarburos 2018; Venezuela: Offshore 2015, NOAA Earth Observation Group 2018.



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