



Revising the marine range of the endangered black-capped petrel *Pterodroma hasitata*: occurrence in the northern Gulf of Mexico and exposure to conservation threats

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ABSTRACT: The black-capped petrel *Pterodroma hasitata* is an Endangered seabird endemic to the western North Atlantic. Although estimated at ~1000 breeding pairs, only ~100 nests have been located at 2 sites in Haiti and 3 sites in the Dominican Republic. At sea, the species primarily occupies waters of the western Gulf Stream in the Atlantic and the Caribbean Sea. Due to limited data, there is currently no consensus on the geographic marine range of the species although no current proposed ranges include the Gulf of Mexico. Here, we report on observations of black-capped petrels during 2 vessel-based survey efforts throughout the northern Gulf of Mexico from 2010–2011 and 2017–2019. During 558 d and ~54 700 km of surveys, we tallied 40 black-capped petrels. Most observations occurred in the eastern Gulf, although birds were observed over much of the east–west and north–south footprint of the survey area. Predictive models indicated that habitat suitability for black-capped petrels was highest in areas associated with dynamic waters of the Loop Current. We used the extent of occurrence and area of occupancy concepts to delimit the geographic range of the species within the northern Gulf. We suggest that the marine range for black-capped petrels be modified to include the northern Gulf of Mexico, recognizing that distribution may be more clumped in the eastern Gulf and that occurrence in the southern Gulf remains unknown due to a lack of surveys there. To date, however, it remains unclear which nesting areas are linked to the Gulf of Mexico.

KEY WORDS: Area of occupancy · AOO · Black-capped petrel · Extent of occurrence · EOO · Geographic range · Gulf of Mexico · Loop current · *Pterodroma hasitata* · Vessel surveys

1. INTRODUCTION

One of the most fundamental needs for wildlife conservation planning is a map of the geographic range of the species of interest (Noss et al. 1997, Mota-Vargas & Rojas-Soto 2012). Without such information,

conservation threats cannot be identified and our ability to prioritize conservation actions, mitigation measures, and research is limited (Underhill & Gibbons 2002, Gibbons et al. 2007, Limiñana et al. 2015). Although the concept of geographic range is familiar to most ecologists, the practice of delimiting and

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measuring the geographic range of a species is not straightforward, and a standardized approach for the delimitation of the area of distribution is lacking (Gaston 2003, Gaston & Fuller 2009, Mota-Vargas & Rojas-Soto 2012). Gaston (1991) defined 2 aspects of the range of a species: extent of occurrence (EOO) and area of occupancy (AOO). The EOO represents the outermost geographic limits of the distribution or occurrence of a species; this boundary is an irregular contiguous line, typically determined from the interpolation of marginal occurrences (e.g. a minimum convex hull; Gaston & Fuller 2009, Mota-Vargas & Rojas-Soto 2012). The EOO typically includes discontinuities (i.e. areas where the species may not have been observed but that lie within the outer bounds of marginal occurrences) and thus represents the overall geographic spread of the localities at which a species is found. In contrast, the AOO is a subset of the EOO and represents the area within the aforementioned outermost limits where the species occurs more regularly. The AOO can be considered as the within-range occupancy pattern or the area within the EOO with environmental conditions that are likely to meet some set of ecological requirements of the species (Boitani et al. 2008, Gaston & Fuller 2009).

For many threatened and endangered avian species, the primary tools used to delimit the geographic range are location-specific surveys and individual-based tracking. Surveys typically use point counts, transects, or newer technologies such as audio recording units or camera trapping to map the occurrence of a species within a focal area (Beirne et al. 2017, Cooper et al. 2019, Ortega-Alvarez et al. 2020, Schroeder & McRae 2020). The range of a species can also be refined based on data obtained from individual tracking efforts, which may also be used to locate previously unidentified or remote breeding or nonbreeding areas (Kanai et al. 2002, McCloskey et al. 2018), determine residency time within an area, or identify interactions of individuals with conservation threats (Jodice et al. 2015, Lamb et al. 2018, Phillips et al. 2018). More recently, citizen-science data, such as eBird (www.ebird.org), have been used to assist in delimitation of the geographic range of a species by providing unique sightings (Cooper et al. 2019).

Delimiting the geographic range of a species is typically done via expert opinion (e.g. many range maps in field guides), plotting known observations on a mapped area (e.g. point-to-grid), species distribution models (SDMs), or a hybrid approach using more than one of the above (Graham & Hijmans 2006, Boitani et al. 2008, Attorre et al. 2013). Delimiting the range of cryptic, secretive, or rare species can be par-

ticularly challenging because basic natural history data are often lacking (Mota-Vargas & Rojas-Soto 2012). Such is the case for many pelagic seabirds that, during the breeding season, can forage 100s to 1000s of km from nest sites, while during the nonbreeding season individuals can range over entire ocean basins (Phillips et al. 2007, Jodice & Suryan 2010, Rayner et al. 2010). Vagrant locations for seabirds are also not uncommon, although when data are sparse it may be challenging to discern a vagrant location from one at or near the edge of the EOO. The dynamic nature of marine environments also results in temporal and spatial shifts in habitat that can challenge our understanding of the spatial and temporal distribution of seabirds. Therefore, range maps for pelagic seabirds are often lacking in detail, making spatially explicit assessments of conservation threats challenging to undertake (Opper et al. 2012, Jodice et al. 2019). For example, the extensive ranging behavior of seabirds exposes individuals to a wide array of marine threats including oil and gas activity (Haney et al. 2017), bycatch mortality from fisheries operations (Anderson et al. 2011), and pollution events (Provencher et al. 2020). These threats often occur across multiple political boundaries or in international waters, the latter of which can be poorly monitored and regulated (Jodice & Suryan 2010). The combination of poorly defined marine ranges and transboundary marine threats adds to the conservation challenges faced by many species of pelagic seabirds.

Among seabirds, one of the least studied and most threatened groups are the gadfly petrels *Pterodroma* spp., which often nest on remote islands and inhabit pelagic waters both near and distant to their nesting areas. The Atlantic Ocean supports 11 species of gadfly petrel (Ramos et al. 2017), 2 of which are extant and breed in the western North Atlantic (*P. cahow* and *P. hasitata*). Here, we focus on black-capped petrel *P. hasitata* (also known locally as Diablotín). Simons et al. (2013) provide a thorough review of the biology and conservation of the species and Satgé et al. (2020) of nesting habitat relationships. This species is considered globally Endangered (BirdLife International 2020; hereafter, any reference to the species as endangered refers to its global status) and is under consideration for listing as Threatened with 4(d) under the US Endangered Species Act (USFWS 2018). Black-capped petrels nest in burrows and crevices in the understory of montane forests at 1500–2000 m above sea level. The breeding season occurs primarily from February–July, with birds dispersing at sea thereafter (Simons et al. 2013). The

black-capped petrel was considered extinct in the mid-1900s but was rediscovered in 1963 when nests were located in the Massif de la Selle of southeastern Haiti (Wingate 1964). Since that time, ~100 nests have been found ($n = 2$ sites in Haiti, 3 in the Dominican Republic; Fig. 1). The nesting area in Valle Nuevo in the Cordillera Central of the Dominican Republic was documented to support nesting only as recently as 2018. Nesting is suspected in Dominica and Cuba but has yet to be confirmed.

At sea, most of what is known about the range of the species is based on observations from vessel-based surveys in the western North Atlantic (Haney 1987, Simons et al. 2013, Winship et al. 2018) and recent efforts to track individuals (Jodice et al. 2015, Satgé et al. 2019). These data sets primarily place the range of the species in the western North Atlantic between ~30–40°N latitude and west of the Gulf Stream, although waters east of the Gulf Stream and in the Caribbean Sea also were highlighted as use areas via tracking data. Based on these data, several sources have developed expert-drawn range maps for the species, and while each differs slightly, all

focus on waters west of the Gulf Stream and none include extensive or definitive use of the Gulf of Mexico (hereafter Gulf) (Fig. 1). For example, BirdLife International (2020) estimates the EOO for black-capped petrels at 9 060 000 km² (i.e. the areal extent of their range map in Fig. 1) but includes only the far eastern reaches of the Gulf. The species also occurs in both a light and dark color morph (Howell & Patten 2008); it is unclear, however, if the ranges of these 2 morphs are similar or disparate either spatially or temporally (Simons et al. 2013).

We used data from 2 vessel-based survey efforts to assess the geographic range of the Endangered black-capped petrel in the northern Gulf. We used a hybrid approach of mapped points, utilization distributions (UDs), and SDMs to delimit the EOO, the AOO, and a core use area within the northern Gulf (Graham & Hijmans 2006, Boitani et al. 2008, Gaston & Fuller 2009). We also used SDMs to describe habitat relationships in the northern Gulf. The EOO represents the limits to the geographic distribution of the species given our current state of knowledge, while the AOO and core use area provide insight into distributional pat-

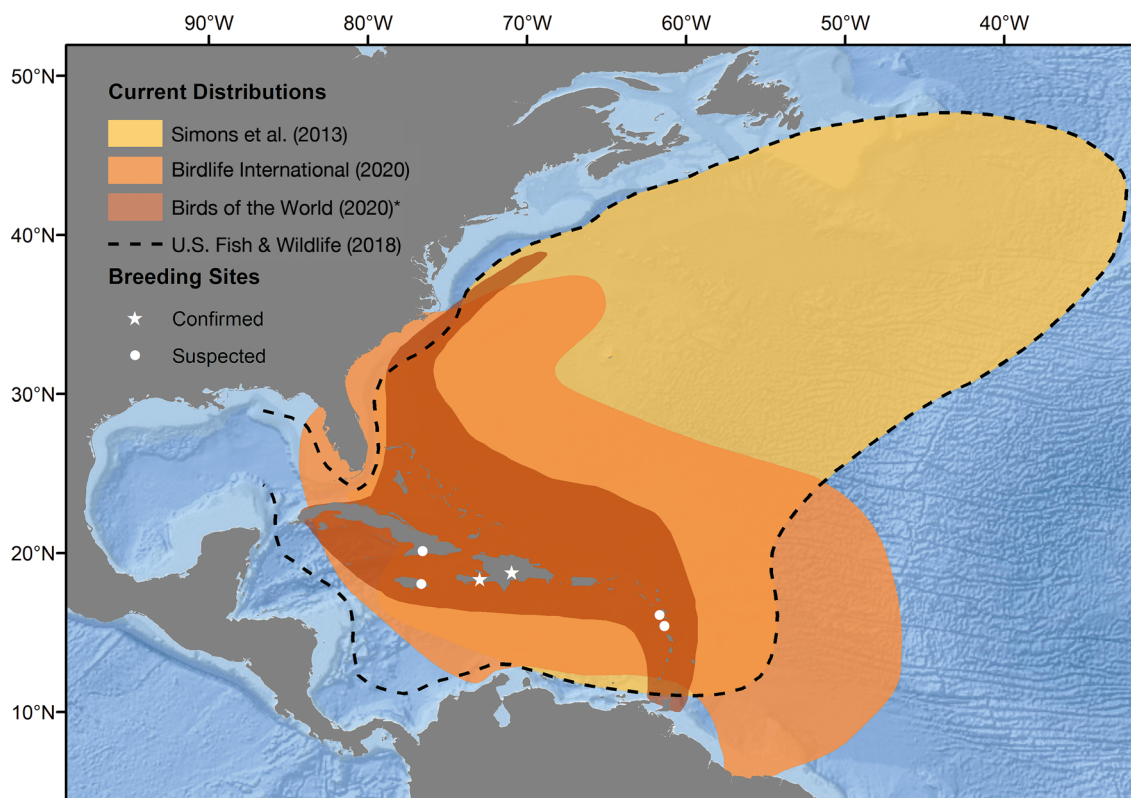


Fig. 1. Breeding locations and marine range of black-capped petrel *Pterodroma hasitata*. Breeding sites are labeled as suspected (e.g. evidence of black-capped petrel presence based on audio or radar surveys) or confirmed. The marine range differs among 4 primary sources and each is displayed for reference. Credit for base map: ESRI, Garmin, GEBCO, NOAA, NGDC, and other contributors. Shades of blue (light to dark) indicate increasing water depth. *See Farnsworth (2020)

terns within the EOO (Gaston & Fuller 2009, Jiménez-Alfaro et al. 2012, Sansom et al. 2018). These data represent a substantial refinement of the marine range of a globally Endangered species and do so in a region with extensive offshore oil and gas development.

2. MATERIALS AND METHODS

2.1. At-sea surveys

Observations of black-capped petrels in the northern Gulf were collected during vessel-based surveys for pelagic seabirds conducted as part of 2 survey programs (Table S1 in the Supplement at www.int-res.com/articles/suppl/n046p049_supp.pdf). Surveys to support the post-spill injury assessment for the *Deepwater Horizon* oil spill Natural Resources Damage Assessment (NRDA) were designed to record occurrences of seabirds and assess mortality and visible oiling (hereafter NRDA cruises; Haney 2011). NRDA cruises ($n = 27$; see Haney et al. 2019 for a detailed description) were conducted in the northern Gulf within the US exclusive economic zone (EEZ) from July 2010–July 2011 by experienced seabird observers (Fig. 2A). Surveys were conducted across 283 d and ~15 300 km of transects (Table S1). Surveys to support the Gulf of Mexico Marine Assessment Program for Protected Species (hereafter GoMMAPPS cruises) sought to model the distribution of seabirds, marine mammals, and sea turtles in the northern Gulf in relation to oil and gas activities among planning areas delineated by the US Bureau of Ocean

Energy Management (BOEM; <https://www.boem.gov/regions/gulf-mexico-ocs-region>). GoMMAPPS cruises ($n = 20$) were conducted in the northern Gulf within the US EEZ from April 2017–September 2019 by experienced seabird observers (Fig. 2B). GoMMAPPS surveys were conducted from NOAA vessels of opportunity that were designed to survey for marine mammals or to collect fisheries/plankton data. Surveys were conducted over 275 d and ~39 400 km of transects (Table S1). Across both efforts, surveys were conducted in each month of the year.

Data collection during each survey program followed a standardized protocol for marine fauna at sea (e.g. Tasker et al. 1984). Briefly, trained observers surveyed for seabirds from a viewing platform (e.g. flying bridge) onboard the vessel, situated ~13–15 m above the sea surface. While the vessel was underway at a speed ≥ 11 km h⁻¹, the observer used $\geq 10\times$ binoculars to identify to the lowest taxonomic level all sitting and flying seabirds within view. Observations were made from the side of the ship with the least glare (i.e. focal side). In both surveys, all seabirds within a 90° forward-facing arc were recorded. During NRDA surveys, seabirds were recorded out to 300 m on a single, ‘focal’ side of the ship. During GoMMAPPS surveys, seabirds were recorded out to 500 m on both sides of the ship. Point counts also occurred occasionally during NRDA surveys when the vessel was stationary for at least 30 min. Relatively low densities of birds and good observation conditions in the Gulf allowed species-specific identification and accurate counts beyond 300 m (e.g. see Spear et al. 2001), although due to restrictions on data collection proce-

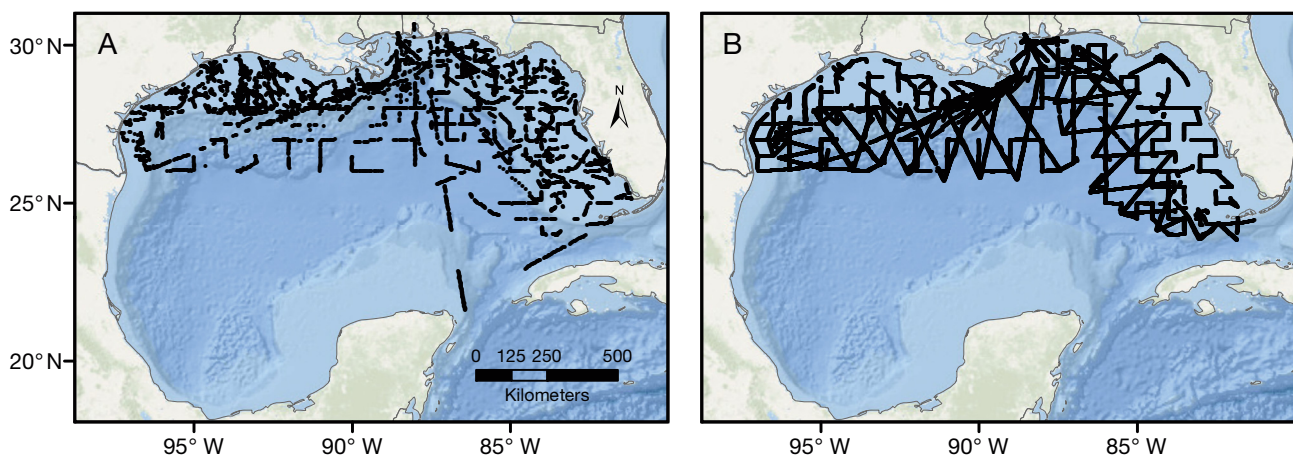


Fig. 2. Spatial footprint of research cruises from 2 research programs in the northern Gulf of Mexico from which black-capped petrels *Pterodroma hasitata* were observed. (A) Surveys conducted in 2010 and 2011 were a component of the post-spill *Deepwater Horizon* Natural Resources Damage Assessment; (B) surveys conducted in 2017–2019 were a component of the Gulf of Mexico Marine Assessment Program for Protected Species. Credit for base map: ESRI, Garmin, GEBCO, NOAA, NGDC, and other contributors. Shades of blue (light to dark) indicate increasing water depth

dures during NRDA cruises, a more conservative survey protocol was employed. Because black-capped petrels are primarily surface foragers, we did not need to account for time below the surface or observations missed during diving. During NRDA cruises, observations of seabirds were recorded manually (i.e. paper, voice recording) along with the exact time and later synchronized with the position of the ship as recorded by GPS at 10 min intervals. During GoMMAPPS cruises, observations were recorded in real-time using the software package SEEBIRD (Balance & Force 2016). For each entry, the observer recorded the species, number of individuals, distance bin or approximate distance, associations with other species, behavior, flight direction, flight height, flight angle, and (when possible) age, sex, and plumage. SEEBIRD records the date, time, and GPS location at the time the record is initially 'opened' via direct connection with the ship's navigation system.

To complement our data, we also sought other records of black-capped petrels in the Gulf. We reviewed published literature and reports from seabird surveys conducted during the GulfCet I and II programs (Davis & Fargion 1995, Ribic et al. 1997, Davis et al. 2000). We also reviewed compilations that included seabirds (Duncan & Havard 1980, Clapp et al. 1982) and a monograph focused on the black-capped petrel (Simons et al. 2013). Lastly, we searched eBird for records of black-capped petrels.

2.2. Spatial and habitat modeling

All observations from both survey efforts were plotted. We then calculated 50 and 90% UDs with kernel density estimation for all observation records from NRDA and GoMMAPPS using the 'adehabitat' package in R (Calenge 2006). The 50% UD can be interpreted as a core use area within a more broadly defined 90% use area (Sansom et al. 2018). We also constructed a minimum convex polygon (MCP) but slightly modified its northern border so as not to include land.

We modeled the relative probability of occurrence of black-capped petrels based on habitat suitability in the northern Gulf using the maximum entropy approach in Program Maxent version 3.4.2 (https://biodiversityinformatics.amnh.org/open_source/maxent/; Phillips et al. 2006). Briefly, Maxent is a machine learning technique that estimates the relative probability of occurrence of a species across a specified area based on observations and a set of covariates (i.e. predictor variables that represent habi-

tat conditions). Maxent performs well at relatively low sample sizes (i.e. <100 observations) by utilizing a presence-background algorithm that is less sensitive to sample size compared to other approaches used to model species distributions (Phillips et al. 2006, Wisz et al. 2008). Maxent is well suited in situations when observation effort is unknown or difficult to characterize (Phillips 2017). We chose to model only presence records (i.e. as opposed to modeling both presence and pseudo-absence data) due to dissimilarities in the documentation of survey effort between NRDA and GoMMAPPS which prevented a fully standardized and comparable description of observation effort.

Using the Maxent interface, we estimated the relative probability of occurrence of black-capped petrels (based on habitat suitability, from 0 to 1) across the entire Gulf (i.e. 'cloglog' output in Maxent). Data were modeled at a spatial resolution of 4.67 km based on the finest resolution available across the selected environmental data (see below for details). Model fitting used 10 000 Maxent-selected random background points across the entire Gulf. As observations occurred in only a portion of the study area, we applied 'clamping' which, in Maxent, assumes that covariates from background pixels with values outside of the range of those from the training data can occur, but at low probabilities (i.e. at the tail end of the distribution; Phillips et al. 2006). Clamping thus reduces the potential for predicting a high relative probability of occurrence in areas with covariate values well outside of those in the training data. We assessed model performance by separating the observations into randomly selected training and testing data sets (75/25% split, respectively). We fit the model to the training data and then applied the fitted model to the test data. We used the area under the receiver operating characteristics curve (AUC) to quantify the predictive power of the model, where an AUC of 0.5 indicates no predictive power and an AUC of 1 indicates perfect discrimination (Bradley 1997). The percent contribution is used as a heuristic estimate of the relative contribution of a given variable to the model (Phillips 2017). We characterized the permutation importance of each covariate (the sensitivity of the model to a given covariate, holding all other covariates constant) using a jackknife procedure.

We modeled observations of black-capped petrels in relation to environmental variables which were selected based on habitat relationships described for black-capped petrels in the Gulf Stream of the western North Atlantic (Haney 1987, Winship et al. 2018) and on other surface-feeding seabirds in the Gulf (Poli

et al. 2017). Each variable was calculated as the temporal average based on the conditions for each date when a black-capped petrel was observed, weighted by the number of presence records of petrels on a given date. This approach created a single spatial layer for each variable, which we used to predict the relative probability of occurrence of black-capped petrels. We obtained the daily variables of sea-surface temperature, sea-surface salinity (SSS), sea-surface height (SSH), and surface current velocity (eastward, u , and northward, v) from the Hybrid Coordinate Ocean Model with Navy Coupled Ocean Data Assimilation (HYCOM + NCODA) Gulf of Mexico 1/25° Analysis (<https://www.hycom.org/hycom>). HYCOM is a generalized (hybrid isopycnal/ σ/z) coordinate ocean model (Chassignet et al. 2009, Metzger et al. 2017), and data assimilation is performed using the NCODA system (Cummings 2005). Surface current velocity was also used to calculate absolute current strength and current direction, each of which was subsequently included in the Maxent model as a covariate. Although we considered including chlorophyll a (chl a) as a predictor variable, spatial gaps in coverage would have resulted in the omission of observations of petrels. Preliminary assessments revealed that including chl a did not improve model performance, and we therefore excluded chl a from subsequent analyses. Lastly, we included average depth as calculated from the SMRT30+ version 6.0 30 arc second data set (Becker et al. 2009). We aggregated each variable to the coarsest native spatial resolution available across all variables (~4.67 km). Therefore, the spatial resolution of the subsequent model (i.e. the resolution at which occurrence probability can be interpreted) is 4.67×4.67 km, which is comparable to similar data sets from vessel-based surveys in the western North Atlantic (e.g. Winship et al. 2018). The degree of covariance and correlation between environmental covariates was assessed using the Band Collection Statistics tool in ArcMap 10.8 (ESRI). None of the covariates exceeded the Pearson's correlation coefficient of $|0.75|$ threshold for exclusion. Thus, all covariates were retained. Unless otherwise noted, covariates were processed in R version 4.0.3 (R Core Team 2020).

2.3. Delimiting the geographic range

We used a combination of previous records of sightings, data from our 2 survey efforts, UD, and results from the Maxent model to assess whether and to what extent the northern Gulf might be considered within

the marine range of the black-capped petrel. First, we qualitatively assessed the spatial and temporal extent of previous records and observations during our surveys to determine if including the northern Gulf within the EOO for the species appeared warranted. Within the study area, a local EOO was delimited by constructing an MCP that circumscribed all locations (i.e. the marginal occurrences of the species; Mota-Vargas & Rojas-Soto 2012, Attorre et al. 2013) but omitted areas over land. We used the 90% UD and SDM to delimit 2 alternate AOOs within the EOO. Delimiting an AOO provides a process by which discontinuities in occupancy can be identified (Gaston & Fuller 2009). Delimiting an AOO from the UD results in an observation-based AOO (i.e. based only on localities of known occurrences), while delimiting an AOO from the SDM results in a potential AOO which allows for inferred or projected sites of occurrence to be considered and is less dependent on the number of occurrences (Jiménez-Alfaro et al. 2012, Attorre et al. 2013). Here, we delimited an observation-based AOO using the 90% UD and a potential AOO by identifying habitat that was moderately or highly suitable (Boitani et al. 2008), which we defined as ≥ 0.65 in our Maxent model. We chose this threshold based on an assessment of known locations in relation to habitat suitability scores, with 50% of our locations occurring in habitat scored ≥ 0.65 . Lastly, we delimited the 50% UD to highlight a core use area within the EOO (Sansom et al. 2018).

3. RESULTS

3.1. Previous records in the Gulf

We searched published literature and reports for previous records of the species in the Gulf. Neither systematic surveys nor compilations of records noted any definitive observations of black-capped petrels at sea in the Gulf from ~1900–2010, although several opportunistic observations from pelagic birding trips were recorded (Table 1, Fig. 3A; ~9–11 records from the mid-1990s and 2010s). Two of these birding records, in November 2016 and January 2017 and each occurring ~220 km southeast of Galveston Bay, Texas, USA (~27.5° N, 94.3° W), are the only records of black-capped petrels in the Gulf during those months (see below). Other efforts to summarize observations of black-capped petrels at sea have a restricted range (e.g. Leopold et al. 2019 in the Caribbean Sea, Winship et al. 2018 in the Atlantic) and therefore do not include waters of the Gulf.

Table 1. Records of black-capped petrels *Pterodroma hasitata* in the Gulf of Mexico not including surveys from the post-spill *Deepwater Horizon* Natural Resources Damage Assessment or the Gulf of Mexico Marine Assessment Program for Protected Species. (*) indicates observations were mapped in Fig. 3. na: a specific area was not defined and is therefore not available

Source type/source	Years and seasons reported	Descriptive location	Approximate area	Number of recorded black-capped petrels
At-sea surveys				
Davis & Fargion (1995)	1992–1994 All seasons	Western and north central Gulf	26–29° N, 87–97° W	n = 0 (although 1 unidentified petrel noted)
Ribic et al. (1997)	1992–1993 All seasons	Western and north central Gulf	26–29° N, 87–97° W	n = 0
Davis et al. (2000)	1996–1997 Spring, summer, winter	Western and north central Gulf	26–29° N, 87–97° W	n = 0
Compilations				
Duncan & Havard (1980)	~1954–1980	Northern Gulf	26–29° N	n = 1 unidentified petrel (eastern Gulf)
Clapp et al. (1982)	1900–1980	Northern Gulf	na	n = 1 mortality ~65 km inland, Leon County, Florida, Fall 1964
Simons et al. (2013)*	1900–2011	Entire Gulf	na	n = 2 ~100 km off Port O'Connor, Texas, May 1994 and July 1997 n = 1 beach recovery, Florida Gulf coast, Fall 2011
eBird*	Prior to Nov 2020	Entire Gulf	na	n = 2 ~ Dry Tortugas Florida, April 2011 n = 1 ~ Key West near shelf break, April 2017 n ~4 birds ~220 km SE Galveston Bay, November 2016 (n = 1–3) and January 2017 (n = 1)

3.2. Survey data

Observations made on NRDA cruises totaled 9 black-capped petrels (Tables 2 & S1, Fig. 3A); 6 as singletons and one observation of 3 birds. One light-morph individual was observed in July 2010 in the eastern Gulf. Eight of the petrels observed during NRDA cruises occurred in waters east of the Mississippi River delta, while one bird was observed just west of the delta. Seven of the 8 observations occurred in waters over the continental shelf break and slope. The southern extent of observations occurred slightly south and west of the western extent of the Florida Keys. We observed petrels in February–May and July–September. Petrels were not observed during cruises in October–December or in June.

Observations made on GoMMAPPS cruises totaled 31 black-capped petrels, 27 as singletons and 2 observations of 2 birds (Tables 2 & S1, Fig. 3A). Three of the petrels observed on GoMMAPPS cruises were classi-

fied as light-morph individuals (March and August 2018 in the eastern Gulf). Most observations of black-capped petrels occurred in the eastern Gulf, east of 88° W longitude, although birds were observed over much of the east–west and north–south footprint of the survey area. We observed petrels in March–May and July–September. We did not observe birds on cruises in January–February, June, or October.

3.3. Use areas and predictive models

The MCP based on our survey data extends from 30–23° N and ~95–81° W (Fig. 3B). The 50 and 90 % UD highlight discontinuities of locations within the MCP (Fig. 3B). The 90 % UD is located primarily west of the Florida Shelf and east of the central northern Gulf (~90° W) but also includes discontinuous nodes in the western northern Gulf. The 50 % UD (i.e. core area within the northern Gulf) is comprised of one

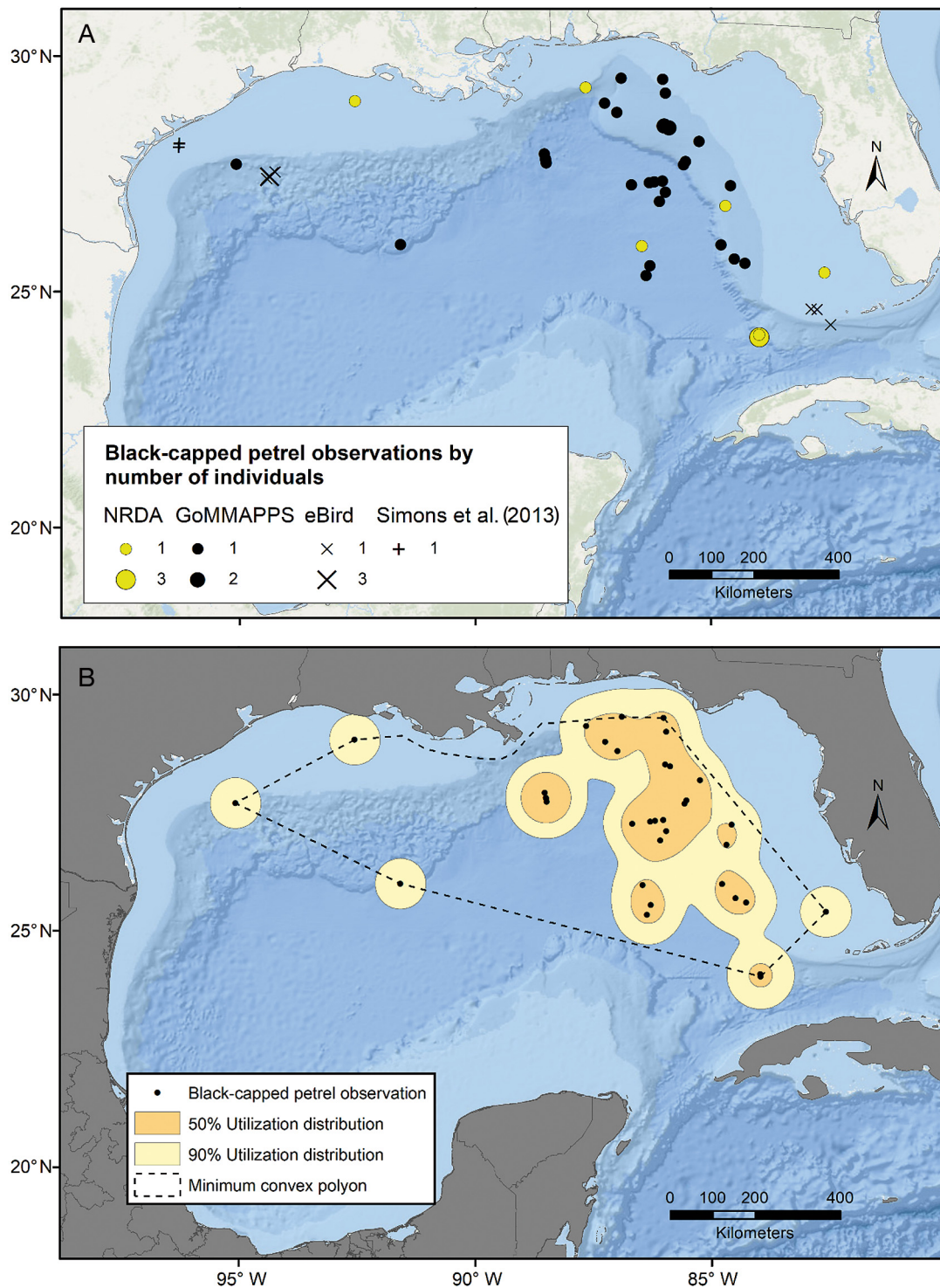


Fig. 3. (A) Locations of black-capped petrels *Pterodroma hasitata* observed during research cruises in the northern Gulf of Mexico and records from opportunistic observations (eBird and Simons et al. 2013; see Table 1). (B) Utilization distributions and minimum convex polygon (with northern border modified to exclude land) for black-capped petrels in the northern Gulf of Mexico (based on survey data from research cruises only; opportunistic observations from Table 1 not included). Surveys conducted in 2010 and 2011 were a component of the post-spill *Deepwater Horizon* Natural Resources Damage Assessment (NRDA); Surveys conducted in 2017–2019 were a component of the Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS). Credit for base map: ESRI, Garmin, GEBCO, NOAA, NGDC, and other contributors. Shades of blue (light to dark) indicate increasing water depth

Table 2. Black-capped petrels *Pterodroma hasitata* observed during research cruises from 2 research programs in the northern Gulf of Mexico. Surveys conducted in 2010 and 2011 were a component of the post-spill *Deepwater Horizon* Natural Resources Damage Assessment (NRDA). Surveys conducted in 2017–2019 were a component of the Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS). Detections refer to an observation of ≥ 1 black-capped petrel

Date observed	No. of detections	Count of individuals within detection
NRDA		
14 Jul 2010	1	1
15 Jul 2010	1	1
10 Aug 2010	1	1
7 Sep 2010	1	1
24 Feb 2011	1	1
3 May 2011	2	3,1
SUM	7	9
GoMMAPPS		
18 May 2017	1	1
23 Jul 2017	2	1,1
26 Jul 2017	1	1
10 Aug 2017	4	1,1,1,1
21 Aug 2017	1	1
11 Mar 2018	1	1
14 Mar 2018	1	1
29 Apr 2018	1	1
4 May 2018	1	1
15 Aug 2018	1	1
19 Aug 2018	2	1,1
22 Aug 2018	1	1
23 Aug 2018	2	1,1
24 Aug 2018	4	1,1,1,1
26 Aug 2018	1	1
27 Aug 2018	2	2,2
16 Sep 2018	1	1
5 Sep 2019	1	1
11 Sep 2019	1	1
SUM	29	31
TOTAL	36	40

larger and 5 smaller and separate use areas, most of which are east of $\sim 88^\circ$ W.

Our predictive model was relatively robust and generated an average AUC value of 0.909 for the training data set and 0.775 for the testing data set, indicating excellent and good model performance, respectively (Bradley 1997, Duan et al. 2014). Max-ent identified 3 areas with relatively higher habitat suitability for black-capped petrels (Fig. 4). The most extensive of these occurs just west of the Florida shelf and extends along the north–south length of the Florida peninsula. Modeled habitat suitability also was higher south of the Mississippi River delta and within a narrow east–west band paralleling much of

the Texas and Louisiana continental slope. Areas of lower habitat suitability include shelf/slope and pelagic waters in the central Gulf.

For black-capped petrels in the Gulf, SSS was the most important predictor of habitat suitability, followed by the direction of the current and SSH (Table 3). Habitat suitability was predicted to peak at moderate values of SSH (Fig. 5A), to be higher with south–southeast currents (Fig. 5B), and to increase until a threshold with increasing salinity (Fig. 5C). SSS had the greatest permutation importance, with direction of current and SSH having less importance (Table 3).

3.4. Delimiting the geographic range

The EOO of black-capped petrels in the northern Gulf can be delimited by the MCP that circumscribes our survey data and encompasses an area of $\sim 410\,200$ km² (Fig. 6A). Opportunistic observations of black-capped petrels in the northern Gulf (Table 1, Fig. 3A) suggest the observations we made near the western and southern extent of the study area are not unique vagrants. The observation-based AOO based on the 90 % UD includes one contiguous and 4 isolated areas (Fig. 6B). The potential AOO aligns well with the contiguous portion of the 90 % UD but also includes an area southwest of this portion of the UD where birds were not observed and an area bounded by the 3 isolated western-most portions of the UD (Fig. 6C). The 50 % UD (Fig. 3B) is an indication of the smaller, core use area of black-capped petrels within the study area.

4. DISCUSSION

Since the early 2000s, most effort invested in improving our understanding of the range of the black-capped petrel has been focused on locating nesting areas and detailing their areal extent. The marine range, in contrast, has been broadly accepted as occurring along the western edge of the Gulf Stream in the western North Atlantic (Simons et al. 2013) and in waters of the Caribbean Sea (i.e. nearby known nesting areas). Use of the Gulf Stream has been confirmed from vessel-based surveys focused primarily in the Mid-Atlantic Bight and South-Atlantic Bight of the USA (Simons et al. 2013, Winship et al. 2018). Use of the Caribbean Sea has not been as well documented (Jodice et al. 2015, Leopold et al. 2019), although all range maps currently in use for the species include this basin. In contrast, the Gulf has yet to

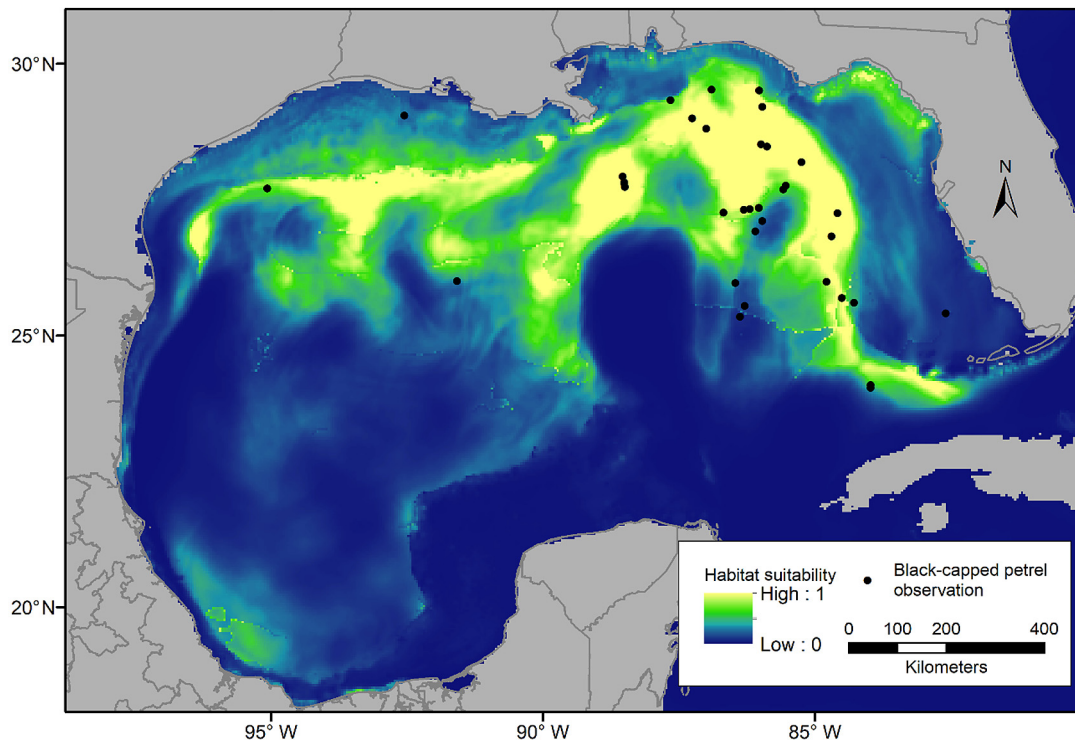


Fig. 4. Predicted probability of black-capped petrel *Pterodroma hasitata* occurrence based on observations from the post-spill *Deepwater Horizon* Natural Resources Damage Assessment and the Gulf of Mexico Marine Assessment Program for Protected Species. Blue shades: low relative probability of occurrence; yellow shades: high relative probability of occurrence based on habitat suitability

be recognized as a regular component of the marine range of the species.

Results from our surveys suggest that a revision to the marine range of the black-capped petrel appears warranted. We tallied 40 individuals across both efforts. Observations included both light- and dark-morph birds and occurred during all seasons of the year. Most observations of the species (i.e. the 50% UD) occurred east of $\sim 90^\circ$ W along the northwestern, northern, and eastern borders of the highly dynamic Loop Current (Sturges & Leben 2000). This region is prone to formation of both frontal eddies and detached rings (Yang et al. 2020). Black-capped petrels are therefore making extensive use of edges along a western boundary current system inside the Gulf, similar to its habits along the western boundary current system along the Gulf Stream in the Atlantic Ocean (e.g. Haney 1987, Simons et al. 2013, Winship et al. 2018). We also recorded 7 observations of black-capped petrels in the central and western portions of the northern Gulf ($\sim 90\text{--}97^\circ$ W). We suggest this region may not be part of the core use area within the Gulf, but the combination of opportunistic sightings (Table 1, Fig. 3), our records, and results from our predictive model suggest that these obser-

vations are unlikely to be vagrant birds. Other procellariids with affinities for warmer ocean habitats, including Audubon's shearwater *Puffinus lherminieri*, band-rumped storm-petrel *Oceanodroma castro*, and Cory's shearwater *Calonectris borealis*, have also been documented to occur regularly in this region of the northern Gulf (GoMMAPPS unpubl. data).

Table 3. Relative contribution of environmental variables to habitat suitability of black-capped petrels *Pterodroma hasitata* in the northern Gulf of Mexico. See Section 2.2 for description of % contribution and permutation importance. Permutation importance sums to 100 across all variables.

SSS: sea-surface salinity; SSH: sea-surface height

Variable	% con-tribution	Permutation importance
SSS (PSU)	41.1	31.3
Current direction (-180 to 180°)	24.2	0.4
SSH (m)	18.5	10.5
Depth (m)	9.7	26.6
Current velocity: v (northward) (m s^{-1})	6.2	31.1
Absolute current strength (m s^{-1})	0.2	0.0
Current velocity: u (eastward) (m s^{-1})	0.1	0.0
Sea-surface temperature ($^\circ\text{C}$)	0.0	0.0

Observations of black-capped petrels in the southeastern portion of our study area are rare but not absent. eBird records include 3 observations in April from inside the western Florida Straits near the Florida Keys and Dry Tortugas. A single black-capped petrel was also observed on 23 April 2011 headed northwards towards the Yucatan Channel southwest of Cozumel Island, Mexico (Haney et al. 2019). Observations of black-capped petrels in these areas would be consistent with likely migratory paths between the Gulf and known breeding sites on Hispaniola. Nonetheless, the breeding location, breeding status, or age of black-capped petrels using the Gulf remain unknown, and no data are available on connectivity between nest sites and Gulf waters. Individuals tracked from nest sites in the western Dominican Republic have not used Gulf waters (Jodice et al. 2015, Satgé et al. 2019). The closest known nesting area to the Gulf is in southern Haiti, although it is suspected that there are nest sites west of this location in southeast Cuba. Our data and other records suggest that black-capped petrels are present in the Gulf throughout the year, although 75% of the individuals we observed in the Gulf occurred during July–September (Table 2), which represents the post-breeding phase (Simons et al. 2013). Our data are not, however, detailed enough to document use of Gulf waters in relation to breeding status or age.

Our models predicted that habitat suitability for black-capped petrels increased primarily with increases in SSS, and to a lesser extent with south and eastward currents and with moderate values of SSH. Black-capped petrels, therefore, appear to be inhabiting waters that represent edges or boundaries of water masses. Spectacled petrels *Procellaria conspicillata* in the eastern South Atlantic also were more abundant over waters with high SSS (Camphuysen 2001). In that region, edges of Agulhas Rings (eddies specific to the conversion zone between the Atlantic and Indian oceans) are characterized by relatively high SSS and strong currents, both of which appear to concentrate prey for petrels. In the Indian Ocean, Barau's petrel *Pterodroma baraui* also tend to be associated with areas characterized by levels of salinity associated with boundaries of water masses (Pinet et al. 2009). Within the Gulf, higher levels of SSS are associated with the dynamic waters of the Loop Current (e.g. compared to waters associated with the continental edge), particularly along the west Florida Shelf (Paluszkiwicz et al. 1983) where we observed the greatest number of black-capped petrels. In the northern Gulf, the presence of squid-eating cetaceans also was associated with higher-

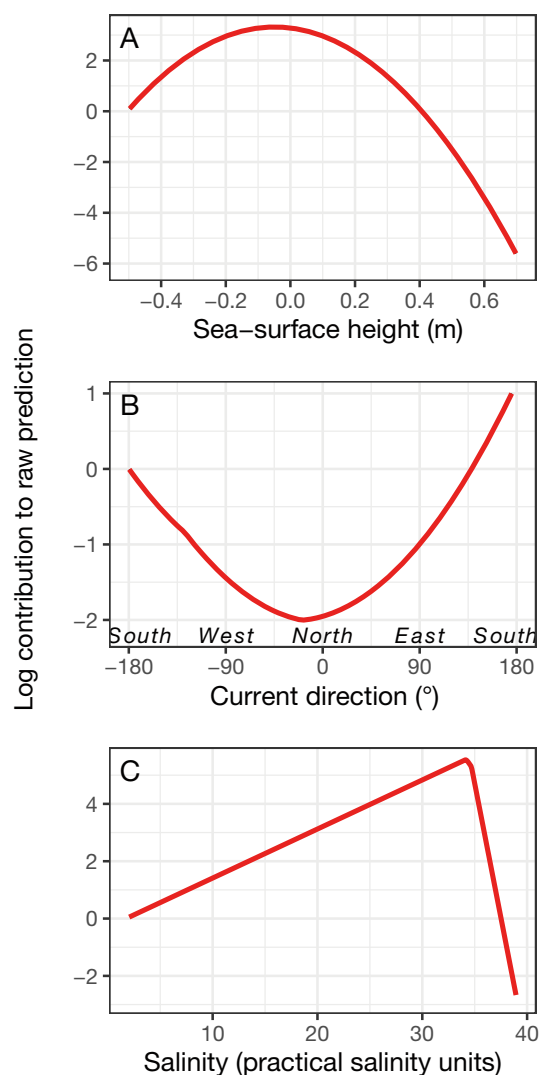
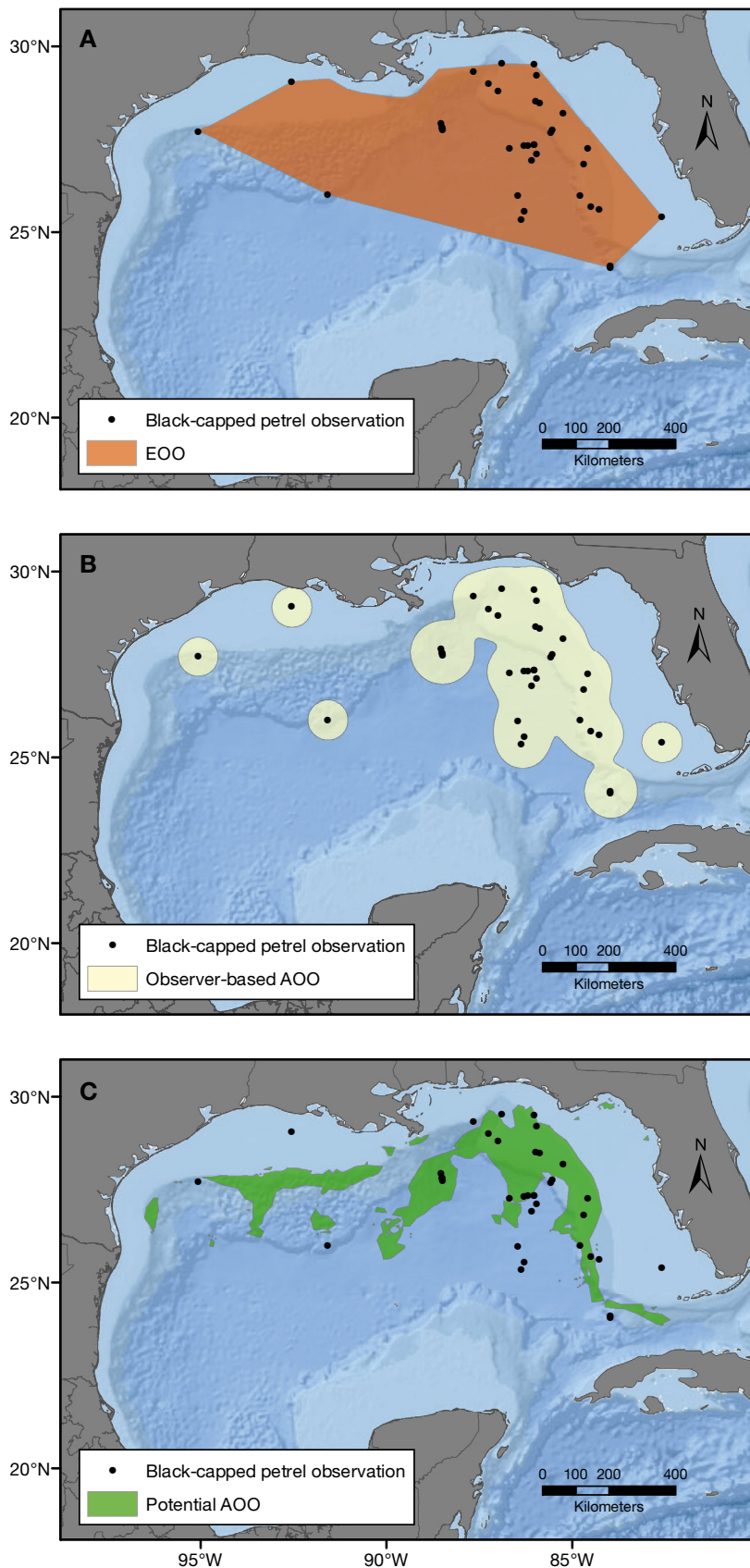


Fig. 5. Response curves of habitat suitability of black-capped petrels *Pterodroma hasitata* in the northern Gulf of Mexico to (A) sea-surface height, (B) current direction, and (C) sea-surface salinity based on models developed in Maxent. Habitat suitability increases along the y-axis (i.e. relatively higher probability of occurrence)

salinity waters (Davis et al. 2002). The other 2 variables of influence identified in our Maxent models, current direction and SSH, also suggest an association with waters that likely concentrate prey. For example, Poli et al. (2017) found that SSH influenced the foraging habitats of masked boobies *Sula dactylatra* and posited that this feature likely serves as a surrogate for availability of forage fish. Although most of our observations occurred over the continental shelf break and slope, our models did not identify depth as a strong predictor, likely due to the wide range in depth that occurs along the shelf break and slope in the Gulf.



While our data are insufficient to quantify conservation threats to the species, we can identify possible threats at the macro scale (i.e. spatial and temporal overlap of a threat and species occurrence; Burger et al. 2011). The Gulf supports substantial levels of activity for the extraction of oil and gas (e.g. ~1800 platforms in federal waters of the northern Gulf alone; <https://www.bsee.gov/faqs/how-many-platforms-are-in-the-gulf-of-mexico>, accessed 10 May 2021), far more than exist in the marine range for the species in the Atlantic or Caribbean Sea, where leasing activities are absent or sparse (BOEM 2012). Three potential conservation threats associated with this high level of oil and gas activity in the Gulf include collision with structures, interaction with produced waters (Middleditch 1984, Ramirez 2005), and direct impacts from both chronic small and acute large oil spills (NOSC 2011). Black-capped petrels are known to collide with lighted towers and structures near breeding sites (Simons et al. 2013), and therefore the potential exists that collisions may occur with lighted structures at sea (Montevecchi 2006). Use of areas adjacent to oil and gas activities may expose individuals to produced waters (i.e. water that is produced as a byproduct during the extraction of oil and natural gas which includes numerous chemical constituents; Veil et al. 2004, Welch & Rychel 2004). Exposure may be direct

Fig. 6. Proposed geographical range of the black-capped petrel in the northern Gulf of Mexico. (A) Extent of occurrence (EOO) based on minimum convex polygon (with northern border modified to exclude land); (B) observer-based area of occupancy (AOO) based on 90% utilization distribution; and (C) potential AOO based on habitat suitability ≥ 0.65 . Observations used for components of the geographical range are those from the post-spill *Deepwater Horizon* Natural Resources Damage Assessment and the Gulf of Mexico Marine Assessment Program for Protected Species surveys (i.e. opportunistic observations from Table 1 not included)

(e.g. contact with contaminated waters; O'Hara & Morandin 2010) or indirect (e.g. ingestion of contaminated prey; Paruk et al. 2016). Petrels also may be exposed to both direct and indirect effects of oiling. Although no black-capped petrels have been recorded as mortalities (e.g. Table 4.7-3 in DHNRDAT 2016) from oil spills in the northern Gulf, based on our data, individual petrels observed during the NRDA vessel survey were within the spatial footprint of the total slick area following the *Deepwater Horizon* blowout. It appears, therefore, that the level of oil and gas activity in the Gulf compared to the Atlantic and Caribbean portions of the range present a more likely threat from oil pollution.

Two other potential threats that may warrant consideration include commercial fishing and cyclonic activity. Commercial fishing activities are spatially and temporally widespread in the Gulf, but the extent to which petrels overlap with this activity is unknown as data with which to evaluate this threat are still relatively sparse. Although the species has not been historically identified in the records of pelagic observer programs in the western North Atlantic, a recent study predicted that black-capped petrels may be at risk of bycatch in the pelagic longline fishery in this region (Simons et al. 2013, USFWS 2018, Zhou et al. 2019). Lastly, the period during which we observed petrels most frequently in the northern Gulf (July–September) coincides with cyclonic activity in this region. Inland records of petrels during hurricane season (i.e. storm-blown birds) suggest that individuals can be directly affected and therefore warrant a mortality risk (Hass et al. 2012). For example, a black-capped petrel was found as a mortality at the base of a television tower ~65 km inland of the Florida Panhandle following a storm in the fall of 1964 (Clapp et al. 1982). Within the Gulf, the relative importance of mechanisms controlling tropical cyclone activity remains unclear, and efforts to model future cyclonic activity in the Gulf are not in agreement with respect to a predicted increase or decrease in activity (Colbert et al. 2013, Knutson et al. 2015, Rodysill et al. 2020). Nonetheless, use of the Gulf by black-capped petrels during hurricane season does appear to pose an additional risk to the species.

Although black-capped petrels occurred in all 4 of the marine ecoregions that comprise the Gulf (Northern Gulf, Southern Gulf, Floridian, and Greater Antilles; Spalding et al. 2007), the species was most likely to occur in the eastern region of the Gulf east of ~88°W. The species also occurs west to ~95°W and south to ~24°N, although in a patchier distribution. Therefore, at a minimum, we suggest that the north-

ern Gulf warrants inclusion within the marine range for the globally Endangered black-capped petrel (i.e. EOO in Fig. 6A) and recognize that a lack of surveys south of the US EEZ make it unclear if black-capped petrels occur in this portion of the Gulf. We suggest that the AOO for black-capped petrels within the northern Gulf be delimited by the moderately to highly suitable habitat generated from the SDM which aligns well with the 90% UD. Use of SDMs to delimit AOOs results in fewer errors of omission and is an acceptable approach, particularly when observations are limited or when species are rare or secretive (Boitani et al. 2008, Gaston & Fuller 2009, Jiménez-Alfaro et al. 2012, Mota-Vazrgas & Rojas-Soto 2012, Attorre et al. 2013). Alternatively, the 90% UD can be used to delimit the AOO (Gaston & Fuller 2009). This approach, however, results in isolated clusters but also limits the probability of making errors of commission (Gaston & Fuller 2009). Lastly, we suggest that the 50% UD represents a core use area within both the EOO and AOO.

The relative importance of the Gulf to black-capped petrels compared to the Atlantic or Caribbean is difficult to discern given differences in data type and availability, survey methods, and survey effort (spatial, temporal, and amount). Nonetheless, some broad comparisons may be made and may provide insights into subsequent opportunities for more detailed and more holistic analyses. Available data suggest that black-capped petrels may occur more regularly throughout the year in the Atlantic and Caribbean basins. The species has been observed in the Atlantic in all seasons, with seasonal hotspots in the South Atlantic Bight (spring, summer, winter) and off the coast of the Outer Banks of North Carolina (summer, fall, winter; Simons et al. 2013, Winship et al. 2018). Black-capped petrels also have been recorded in the Caribbean Sea during all months, although the species appears to occur more regularly during winter and spring (Simons et al. 2013, Jodice et al. 2015, Leopold et al. 2019). In contrast, observations of black-capped petrels in the Gulf are less common from mid-fall through winter (although survey effort was minimal during that time period) and appear to be more common from spring through early fall, with peak observations occurring in August. Breeding birds have been documented in the Atlantic and Caribbean (Simons et al. 2013, Jodice et al. 2015), although it has yet to be documented if the Gulf is used by breeding birds. Interestingly, the distance from known breeding sites on Hispaniola to areas of high use in the Atlantic (e.g. Gulf Stream waters adjacent to Cape Hatteras) are

similar to distances to the core use area we identified in the Gulf (~1800 km).

In terms of abundance, the number of detections of black-capped petrels during our Gulf surveys was of similar order as the number of those found across large expanses of the western North Atlantic. Petrels were observed on 0.29% of all 4 km survey segments in the Gulf and 0.47% in the Atlantic, and we detected ~1 petrel per 1000 km surveyed in the Gulf compared to ~3 per 1000 km surveyed in the Atlantic (cf. synthesis in Winship et al. 2018). These estimates and comparisons should be interpreted cautiously given the differences in survey methods, analytical approaches, and other details pertaining to each data set. Nonetheless, the data do suggest, even conservatively, that while the relative abundance of black-capped petrels appears higher in the Atlantic compared to the Gulf, they are both within the same order of magnitude. Similarly, the median group size of black-capped petrels detected during surveys is the same in the Atlantic and Gulf (median = 1), although the range of group sizes in the Atlantic does appear wider (n = 762 detections, range = 1–75; Northwest Atlantic Seabird Catalog v.0.2.0, accessed 4 May 2021) compared to the Gulf (range = 1–4). Data from the Caribbean also indicate a median group size of 1, but larger groups (25–100) have been observed in nearshore waters off southeastern Cuba (Leopold et al. 2019).

Gaps in our understanding of the complete geographic range for the black-capped petrel at sea still exist. Occurrence and occupancy (i.e. potential EOO and AOO) of waters in the southern Gulf and east of the Gulf Stream in the western North Atlantic remain unclear. Black-capped petrels have been observed in the eastern North Atlantic and within the Canadian EEZ, but the frequency of use there is also not clear. Nonetheless, gadfly petrels in general are highly mobile and rely on marine habitat that is highly dynamic in space and time and often not contiguous in terms of spatial distribution. The definition of a marine range for such a species might best be considered in terms of broad marine areas that offer habitat conditions amenable to foraging and flight, recognizing that birds may transit poor habitat to access distant habitat that is suitable. Therefore, an integration of both known occurrences and probabilistic occurrences based on habitat suitability appears to offer an approach that strikes a balance between the challenges of observing a rare and highly mobile species in remote locations and the predictive and informative nature of habitat modeling (Graham & Hijmans 2006, Mota-Vargas & Rojas-Soto 2012). Furthermore,

as observations increase within the study area, UDs and SDMs can be re-evaluated, and subsequent revisions to the EOO or AOO can be made using transparent approaches. Efforts to deploy tracking devices on breeding black-capped petrels at nest sites (Jodice et al. 2015, Satgé et al. 2019) have improved our understanding of use areas, connectivity between use areas and known nesting areas, and fidelity to and residence time within use areas. To date, however, all tags deployed have been from only one nesting area in the western Dominican Republic, and none of the birds tagged were tracked to the Gulf. Therefore, although our results suggest spatially and temporally widespread use of the Gulf, it remains unclear which of the few remaining nesting areas of black-capped petrels are directly linked to the Gulf.

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