THE BREEDING PHENOLOGY AND DISTRIBUTION OF THE BAND-RUMPED STORM-PETREL *OCEANODROMA CASTRO* ON KAUA'I AND LEHUA ISLET, HAWAIIAN ISLANDS

ANDRÉ F. RAINE[1], MATTHEW BOONE[1], MATTHEW McKOWN[2] & NICK HOLMES[3]

[1]*Kaua'i Endangered Seabird Recovery Project (KESRP), PO Box 81, Hanapepe 96716, Kauai, HI, USA (araine6@hawaii.edu)*
[2]*Conservation Metrics, Inc., Center for Ocean Health, 100 Shaffer Rd., Santa Cruz, CA 95060, USA*
[3]*Island Conservation, 2100 Delaware Ave, Suite 1, Santa Cruz, CA 95060, USA*

Received 8 November 2016, accepted 28 February 2017

ABSTRACT

RAINE, A.F., BOONE, M., McKOWN, M. & HOLMES, N. 2017. The breeding phenology and distribution of the Band-rumped Storm-petrel *Oceanodroma castro* on Kaua'i and Lehua Islet, Hawaiian Islands. *Marine Ornithology* 45: 73–82.

The Band-rumped Storm-petrel (BRSP) *Oceanodroma castro* has a large breeding range, spanning the warmer portions of both the Atlantic and Pacific Oceans. The Hawaiian population is one of the most cryptic and under-studied seabird species in the archipelago, and its breeding phenology and distribution are poorly known. We used several methods, including human auditory surveys, automated acoustic surveys, mist-netting, and data from a seabird rescue and rehabilitation program to assess the breeding phenology and distribution of BRSP on the island of Kaua'i and adjacent Lehua Islet. Our data show that the species arrives at breeding colonies on Kaua'i in late May, with birds fledging from late September to mid-November. Unlike BRSP breeding populations in the Galápagos, Azores, and Madeira, a winter breeding population was not apparent. Breeding colonies were found to be concentrated along the Na Pali coast, particularly within canyons from the Kalalau Valley to Polihale, as well as the Waimea Canyon. These areas are characterized by sparsely vegetated, very steep cliffs. Small pockets of BRSPs were also encountered in some of the wetter and heavily vegetated valleys associated with exposed rocky cliff faces. A large concentration of storm-petrel activity was also recorded on the southeastern slopes of Lehua Islet. A model created to predict Kaua'i-wide distribution indicated that the key predictive variables, found in 85% of all models, were average rainfall, EVI (Enhanced Vegetation Index to assess broad vegetation types), and slope. Identifying this species' breeding phenology, range, and habitat requirements is a key step to inform conservation efforts for BRSPs elsewhere in the archipelago. In that regard, much work remains to be done.

Key words: Hawai'i, Storm-petrel, *Oceanodroma*, breeding phenology, distribution

INTRODUCTION

The Band-rumped Storm-petrel (BRSP) *Oceanodroma castro* has a widespread breeding distribution across tropical and subtropical latitudes of the Atlantic and Pacific oceans (Boersma & Groom 1993, del Hoyo *et al.* 1992, Slotterback 2002). Because of its extensive breeding distribution, the geographic isolation of many of the breeding populations, and the geographic variation in a number of morphological characteristics, some researchers believe that BRSP could consist of several subspecies or even separate species (Harris 1969, Bolton 2007, Friesen *et al*. 2007). Indeed, based on morphology, vocalizations, and genetic analysis, the summer breeding form of what had formerly been considered BRSP from the Azores has since been identified as a distinct species — Monteiro's Storm-petrel *O. monteiroi* (Bolton *et al.* 2007). A global phylogeny assessment, using DNA sequence variation in the mitochondrial control region, has further lent support to the concept that there could be multiple species involved (Smith *et al.* 2007). This possibility is further strengthened by the breeding phenology of different populations. In the Galápagos (Snow & Snow 1966, Harris 1969, Smith & Friesen 2007), Azores (Monteiro & Furness 1998, Bolton 2007), and Madeira (Nunes 2000), two distinct breeding seasons — summer and winter — representing different populations are often found at the same location (see also Friesen *et al*. 2007). Within the Hawaiian Islands, BRSP is a rare and poorly known species, and how it fits within the complex of subpopulations is unknown (Duffy 2010). Because of its rarity in the Hawaiian Islands, the species is listed as "Endangered" by the State of Hawai'i and the US Fish and Wildlife Service (USFWS 2016). The species faces a number of threats throughout its Hawaiian range, including depredation by introduced predators such as rats *Rattus* sp., cats *Felis cattus,* and Barn Owls *Tyto alba* (Harrison 1990, Galase *et al.* 2016, Raine *et al.* 2017), all of which are present throughout the Hawaiian islands, as well as by light attraction (which is known to affect other storm-petrel species; Wiese *et al.* 2001, Montevecchi 2006).

BRSPs may once have been widespread and common throughout the main Hawaiian Islands, as deduced by bones found in middens on Hawai'i, O'ahu, and Moloka'i, which in turn suggests that these birds may have been part of the diet of early Polynesians (Olson & James 1982, Harrison 1990). However, the present-day distribution is uncertain. Potential breeding records span most islands, including Kaua'i (Wood *et al.* 2002), Maui, Hawai'i (Banko *et al.* 1991, Galase *et al.* 2016), Lehua Islet (VanderWerf *et al.* 2007), and Kaho'olawe (Hawai'i Heritage Program 1992). There are no records of the species' habitation on any of the northwestern Hawaiian islands, although there are occasional records at sea (Pyle & Pyle 2009). The vast majority of recent records consist of auditory and visual detections of subadult/adult birds, with the most compelling including (i) the skull of a probable juvenile found on Lehua Islet (VanderWerf *et al.* 2007), and (ii) high levels of activity within Pohakuloa Training Area on Hawai'i. Included in the latter is camera footage of a bird entering an apparent burrow entrance on multiple occasions and the predated remains of a probable chick (Galase *et al.* 2016).

In this paper, we consider the current known distribution of BRSP on Kaua'i (Fig. 1), which is thought to have the largest breeding population in the main Hawaiian islands (Wood *et al.* 2002). We also assess the species' breeding phenology on Kaua'i through the use of automated acoustic sensors, banding records, and data on fledglings collected after light-attraction incidents by the Save Our Shearwaters project. These data are also used to assess whether there could be a summer and winter breeding population. Lastly, we consider records from adjacent Lehua Islet.

METHODS

Human auditory surveys

Between 2006 and 2016, standardized auditory surveys were undertaken by trained observers to identify breeding colonies of threatened and endangered seabirds, including BRSP, on Kaua'i and Lehua Islet. Auditory surveys were carried out 2.0 h after sunset and 1.5 h starting two hours before sunrise, with participants also using night-vision goggles (US Night Vision PVS-7 Gen 3). Surveys were not conducted during full moon periods, as nocturnally active seabirds tend not to be vocal at that time.

Surveys were split into 30-min sessions, with 5 min allotted for the collection of weather data, 25 min for auditory surveying, and 5–10 min for concurrent night-vision surveying. Surveyors were instructed to record all seabird calls (classified as a single unbroken note or series of notes) heard, as well as visual observations during the survey period. For any records, data were collected on time, species, direction and distance from observer, and the behavior of the bird (with particular attention paid to circling and ground-calling).

At the end of surveys, observers created polygons on field maps identifying overall coverage and where seabird activity was apparent. Polygons were categorized as the following three types: "hotspot-heavy," "hotspot-light," and "ground-calling." Ground-calling polygons constituted those in which birds were confirmed calling from the ground (as opposed to from the air), as this is indicative of breeding activity. "Hotspot-heavy" and "hotspot-light" were defined as polygons where there was aerial calling only, with "heavy" denoting continuous calling during the survey and "light" denoting sporadic calling.

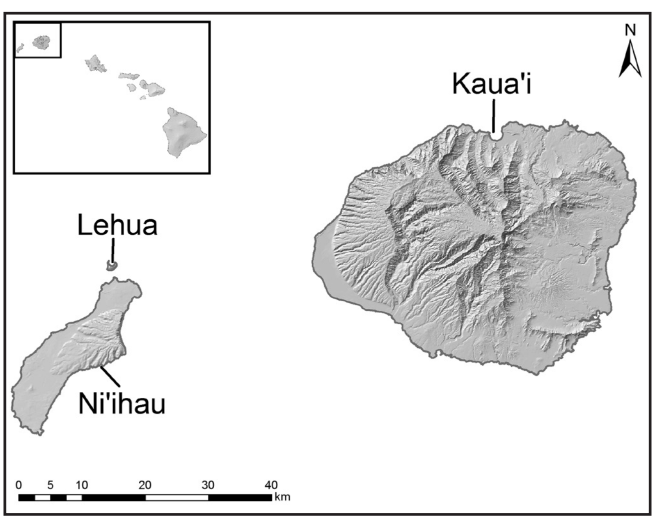

Fig. 1. Map of Kaua'i and Lehua Islet, and their location within the main Hawaiian islands.

Automated acoustic sensors

Between 2011 and 2016, 88 automated acoustic sensors (SongMeter SM2+, Wildlife Acoustics Inc., Concord, MA) were deployed at 69 locations around Kaua'i and 19 locations on Lehua Islet. These sites were known from previous human auditory surveys to hold significant breeding populations of threatened and endangered seabirds, including in some cases BRSP. In most years, acoustic recorders were deployed in April and recovered in September. In 2015, however, six units also operated during winter in areas along the Na Pali coast where previous efforts had identified the highest call rates of BRSP. In all cases, recorders were deployed at least 250 m apart, to prevent the same call being reported concurrently on more than one automated acoustic sensor.

Recorders were powered by four D-cell alkaline batteries and recordings were stored on a 32 GB secure digital (SD) memory card. All recorders were fitted with two omnidirectional microphones, oriented horizontally, and recorded in stereo at a sampling rate of 22.05 kHz. Recorders were deployed using two methods. In more accessible areas, units were deployed by hand and were either mounted on poles 30 cm above the ground or placed directly on the ground, where rocks or stakes were used to stabilize the recorder vertically. Units were oriented to shelter sensor microphones from prevailing winds, and to keep them well away from moving branches and leaves. In rugged and inaccessible areas (such as the Na Pali coast and the steep sides of some of the larger valleys), units were deployed via helicopter. In this case, units were placed in a specially designed wooden box with a large handle and wooden stabilizers, and deployed (and recovered) using a grappling hook.

Units were programmed to record 1 min every 5 min for 5 h after sunset, and 1 min every 10 min for 5 h before sunrise. Programming was undertaken using the SMCONFIG software package. Ground-deployed units were checked once every other month. At each check, SD cards were collected and all batteries changed. Microphones were also checked for functionality, and, if a microphone was malfunctioning, it was immediately replaced. For helicopter-deployed units, recorders were recovered after two months, when SD cards and batteries were switched out, and were then redeployed as needed.

Banding sessions

Between 2012 and 2016, six banding sessions were undertaken targeting BRSPs. These were carried out at two sites where storm-petrel activity had previously been recorded: Nualolo Aina and Waimea Canyon. Banding was undertaken on 22 and 23 August 2012, 4 September 2013, 11 September 2013, 27 June 2016, and 4 August 2016. In all cases, two mist nets (four shelf, 2.6 m × 12 m, 38 mm mesh polyester) were set along ridge lines. Tapes broadcasting BRSP calls were used to attract birds to the nets. Sessions started at sunset and continued for 3–5 h. All individuals caught were assessed for the presence of a brood patch and scored as "none," "full," or "re-feathering." In storm-petrels, re-feathering of brood patches starts a week after hatching (Harris 1969). Captured birds were then fitted with a uniquely numbered, stainless steel bird band and released.

Save Our Shearwaters data

The "Save Our Shearwaters" (SOS) Program, run by the State of Hawai'i, was initiated in 1979 and is currently based at the Kaua'i Humane Society. The program collects seabirds picked up by citizens, and, after assessment of body condition, bands and releases them from coastal locations. A small number of fledgling BRSPs have been collected since the program's inception, as they are sometimes attracted to artificial lights. We used these data to assess the fledging period, as actual nest sites have yet to be found and monitored on the island. We considered only those birds positively identified by SOS personnel as hatch-year BRSPs (based on presence of down and/or immaculate and unworn flight and tail feathers) for this analysis.

Data analysis

Automated acoustic sensors. Automated analysis of field recordings was carried out with custom detection and classification software. The software automates the identification of potential storm-petrel calls in field recordings with a machine-learning technique known as deep neural networks (DNNs). DNNs is a powerful new machine-classification tool used in speech-recognition (Deng *et al.* 2013) and image-recognition applications (Ciresan *et al*. 2012, Krizhevsky *et al.* 2012).

Our approach split all field recordings into 2-s sound clips and 256 frequency bins within each clip. A total of 10 spectro-temporal features were measured within each frequency bin, and feature scores were stored for each clip. A control dataset for training and testing DNN classification results was then created by taking a uniform sample from all 2-s clips on recordings from all field sites, to collect a total of 12 917 clips. All sound clips in the control dataset were manually labeled to note the presence or absence of storm-petrel calls in each clip. The resulting control dataset contained labeled examples of 1 508 positive events (vocalizations from target species), and 11 409 negative events (i.e., examples of other sounds from the soundscape at all survey sites) to train and test the performance of DNNs. The resulting DNN classification model learned which combination of spectro-temporal features best differentiated storm-petrel calls from other sounds. The model returns a probability that each 2-s clip contains a storm-petrel call. The BRSP classification model correctly detected 85% of the storm-petrel calls on the test dataset (i.e., 15% of calls in the test dataset were not detected), and 94% of the events flagged by the model were BRSP calls (i.e., 6% of detections were false positives) at the classification threshold set for this analysis. The trained BRSP classification model was applied to classify potential storm-petrel calls on raw data from all field recordings in the survey, and all events flagged as probable BRSP calls were manually reviewed by an analyst.

Breeding distribution modeling. Polygons showing known distribution of BRSPs were mapped using ArcMap 10.2.2. A presence–absence map was created by overlaying a 250 m grid across the island using the Create Fishnet tool in ArcGIS. Each grid cell was categorized as "present" if it satisified at least one of the following criteria: (i) automated acoustic sensors recorded greater than 0.5 calls/h during June or July; (ii) human auditory surveys noted activity categorized as "Hotspot-heavy," "Hotspot-light," or "Ground-calling" (as outlined above) in an area; and (iii) presence of a brood patch was confirmed on caught individuals. Remaining cells were considered "absent" if audio-recording units, human auditory surveys, or banding was attempted but no BRSP evidence was found.

We collected seven predictors of BRSP presence: (i) elevation, (ii) slope, (iii) aspect x, (iv) aspect y, (v) vegetation cover, (vi) annual rainfall, and (vii) presence of rock. We calculated elevation, slope, and aspect from the Landfire 2010 dataset for Kaua'i (http://landfire.gov). Aspect was split into x and y vectors by converting degrees to radians and multiplying the aspect by sin (x vector) and cosin (y vector). Annual rainfall was downloaded from the State of Hawai'i Office of Planning (http://planning.hawaii.gov/gis/download-gis-data) at a resolution of 250 m. Presence of rock was derived by downloading the 2015 NRCS USDA Soil Survey for Kaua'i (http://websoilsurvey.sc.egov.usda.gov). We used rocky outcrop as a measurement of bare rock, defined as an area where 90% of the cell is free of vegetation. To measure vegetation cover, we used the Enhanced Vegetation Index (EVI) downloaded from the State of Hawai'i Office of Planning. EVI measures the green reflectance of vegetation measured from the MODIS VI satellite, and accounts for canopy characteristics by also accounting for soil characteristics and atmosphere aerosol. Thus, its results are robust in regions with high biomass like Kaua'i (Huete *et al.* 2002). We averaged all variables except slope into each 250 m^2 cell using the Zonal Statistics tool. For slope, the maximum recorded slope was recorded for each grid square.

Using boosted regression trees (BRT; Buston & Elith 2011, Hijmans & Elith 2012), we developed a correlation matrix across all predictors that showed no significant interactions (<0.60 correlation), so all variables were included in model fitting. Seven parameters were considered in the model (EVI, mean rainfall, elevation, slope, aspect u, aspect v, and elevation). BRTs were fitted in R (R Development Core Team 2016 Version 3.4), using the *gbm.step* function in the *dismo* package. This function attempts to increasingly fit larger tree size until a minimum convergence in predictive error is achieved using cross-validation. Anything under 10 000 trees was considered acceptable. Test data showed that a *lr* of 0.005, *tc* of 2, and 3 300 trees minimized predictive deviance; therefore, these were used to fit the final model. We then fit the final model to the entire island of Kaua'i using the *predict* function in R.

Considering the small size of Lehua Islet, we did not attempt to model distribution of the species there, but simply mapped call rates recorded on acoustic recording devices deployed during the study period.

RESULTS

Breeding phenology

Colony attendance. To assess colony attendance patterns, in 2015 automated acoustic sensors were deployed at six sites where storm-petrel activity had been recorded in previous years. Sensors were deployed by helicopter on 7 April 2015 and recovered on 19 February 2016 (with several trips between the two time periods to switch SD cards and batteries). The first storm-petrel detection during this period was on 22 May and the last on 1 October. No calling activity was detected by any sensor during winter. Calling activity peaked in June and August and diminished through the end of September (Fig. 2). Nightly calling activity peaked between 70 min and 130 min after local sunset (Fig. 3).

Prevalence of brood patch. A total of 36 adult BRSPs were caught over the six banding sessions. Brood patches were recorded on 94.6% of birds caught, evident in all banding sessions from 27 June to 11 September (Table 1). During the late August banding session,

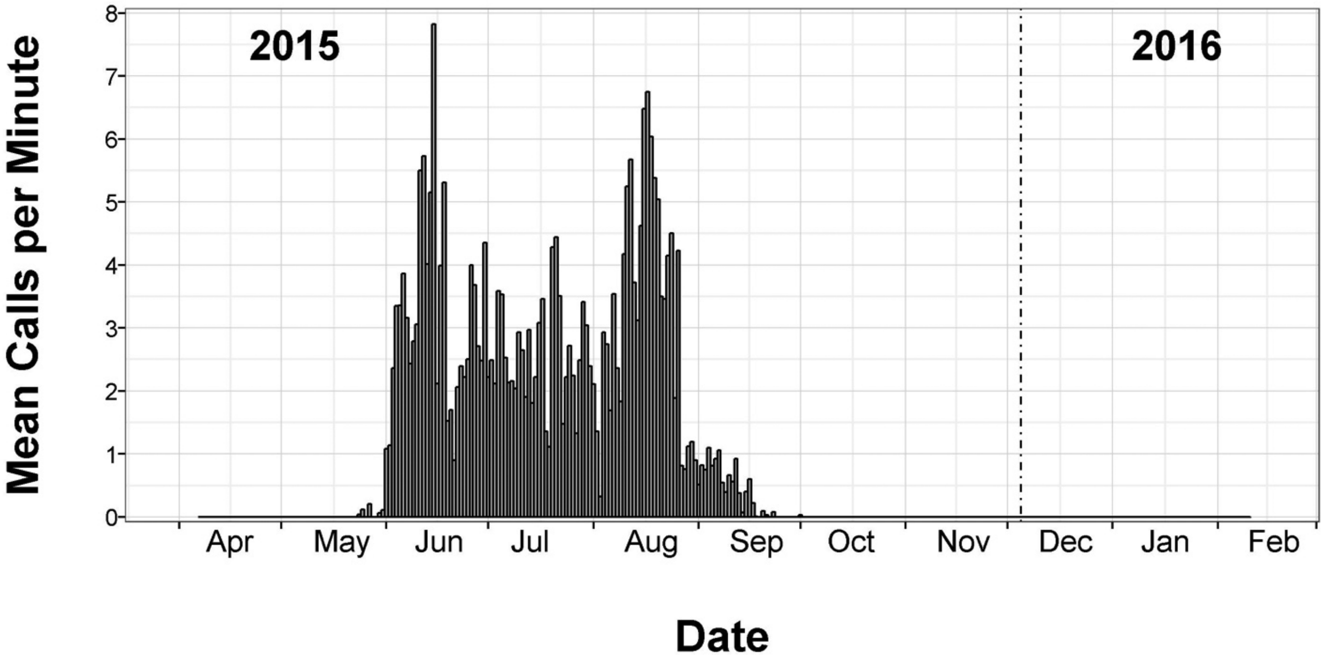

Fig. 2. Mean Band-rumped Storm-petrel vocal activity rates at six survey sites on Kaua'i over the 2015–2016 automated acoustic survey period (from 70 min to 130 min after sunset). Black line at 0 shows survey nights without activity (i.e., April to late May 2015 and October 2015 to mid-February 2016).

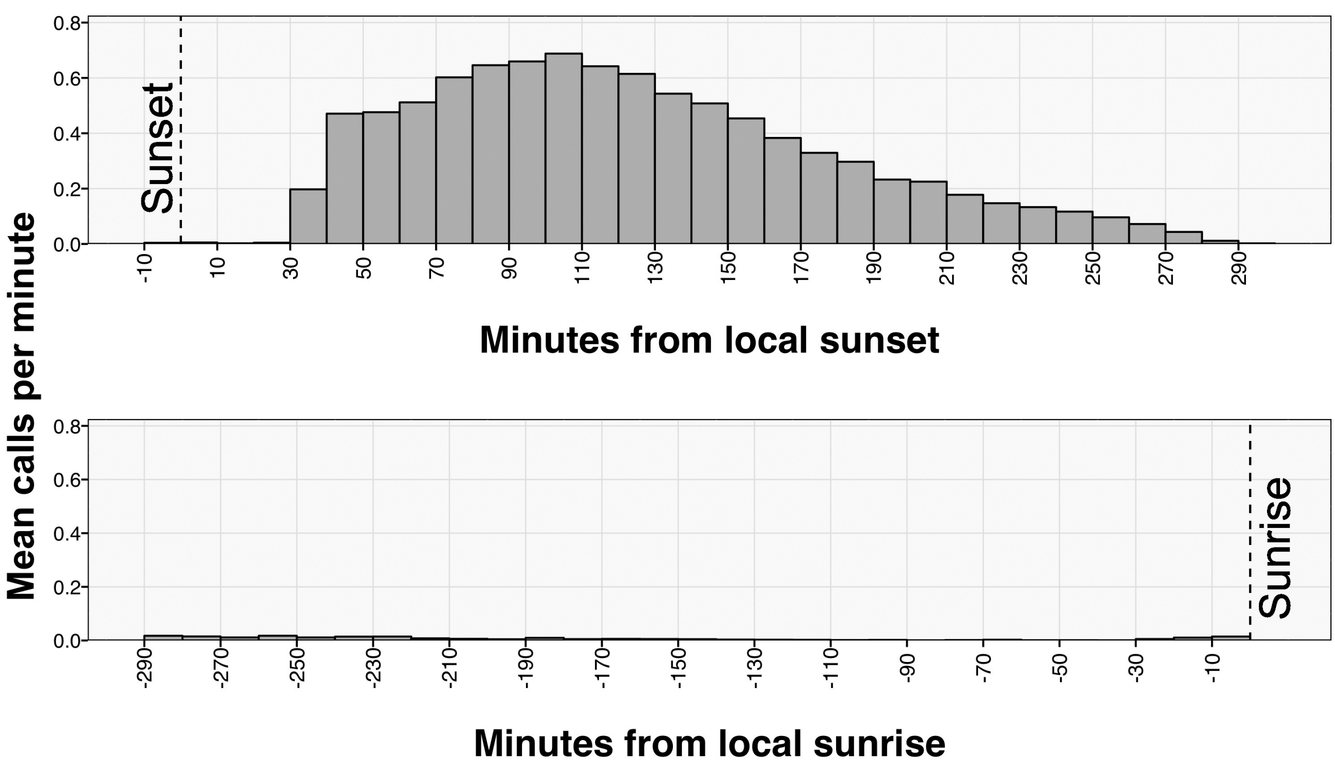

Fig. 3. Band-rumped Storm-petrel vocal activity over an average survey night.

TABLE 1
Prevalence of brood patches on Band-rumped Storm-petrels caught on Kaua'i

			Percentage		
Date	**Year**	**n**	**None**	**Full**	**Re-feathering**
27 Jun	2016	9	22.0	78.0	
4 Aug	2016	1		100.0	
22 Aug	2012	15		80.0	20.0
4 Sep	2013	9		33.3	66.7
11 Sep	2013	1		100.0	

20% of individuals had brood patches, and these were starting to re-feather; of the 10 birds caught in the two September sessions, 60% had re-feathering brood patches.

Fledging period. A total of 23 hatch-year BRSPs were recorded in the SOS database, with records starting in September and continuing into November. They were deemed to be hatch-year birds owing to the presence of down and/or immaculate and unworn flight and tail feathers. The majority of records of fledglings (78.3%) were recorded during October. The earliest bird identified as hatch-year was on 11 September (which was an outlier by 27 d from the next earliest bird), and the latest was on 23 November.

TABLE 2
Breeding phenology of Band-rumped Storm-petrels in Kaua'i

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				Arrival							
				Egg laying	Egg laying	Egg laying					
					Incubation	Incubation	Incubation				
						Guard	Guard	Guard			
								Fledging	Fledging	Fledging	

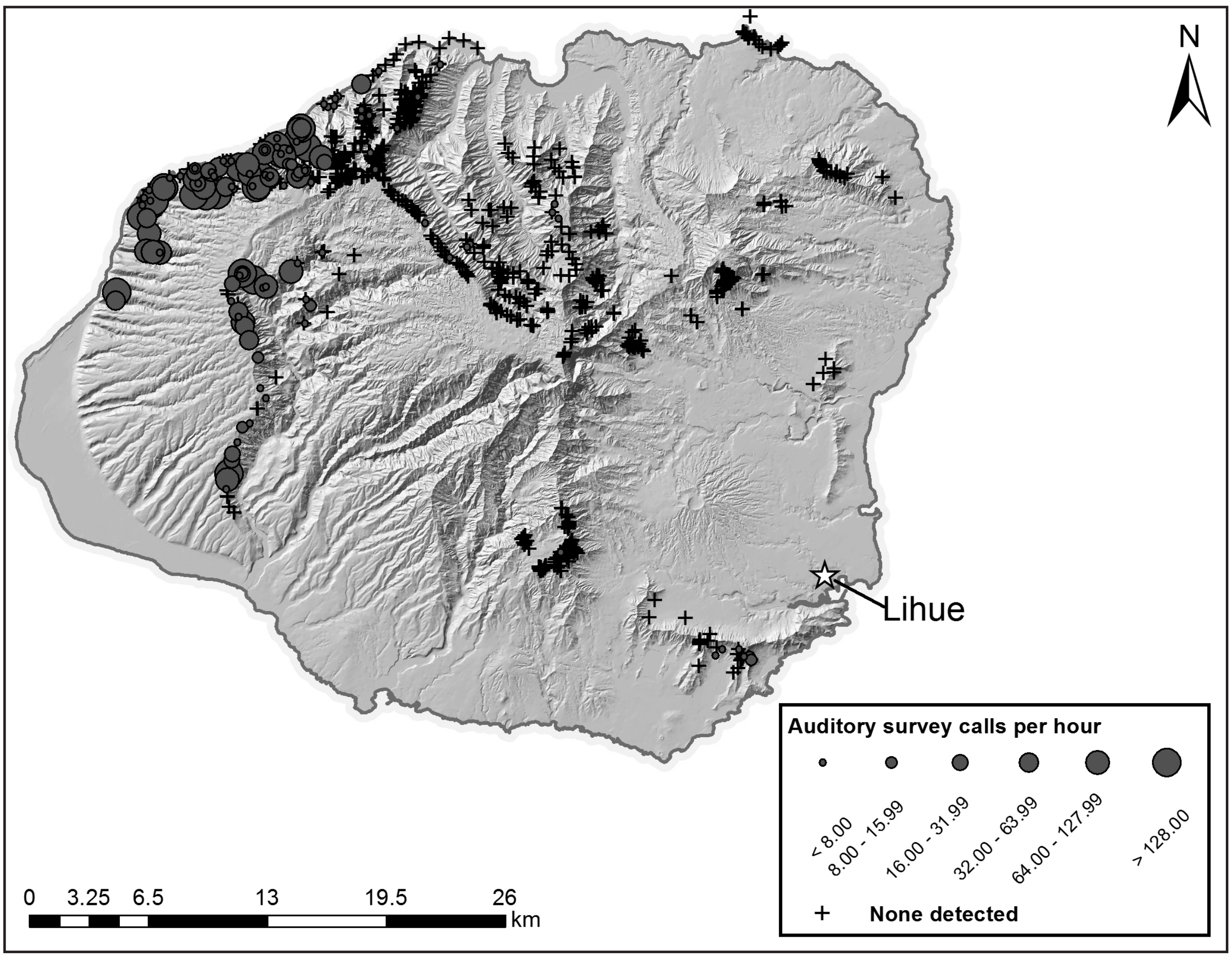

Fig. 4. Band-rumped Storm-petrel call rates detected during auditory surveys, 2006–2015, on Kaua'i.

Overall breeding phenology. According to Harris (1969), incubation in BRSP lasts 42 d and the fledging period is 70–78 d. Breeding seasons for this species (both winter and summer populations) in Madeira last 6–7 mo (Nunes 2000). Based on this and the data provided above, the breeding phenology of the BRSP on Kaua'i is estimated as follows (Table 2). Birds start arriving in late May, with egg-laying in mid-June. Incubation continues until the beginning of August. Birds fledge in October, with the last birds fledging toward the end of November, after which all BRSPs depart breeding sites and head to unknown wintering grounds.

TABLE 3
Relative influence of seven predictors among 3 300 models fit using boosted regression trees

Variable	Relative influence
Rain	29.39
Enhanced Vegetation Index	27.76
Slope	15.61
Elevation	9.44
Aspect x	6.36
Rock	6.10
Aspect y	5.33

CONTEMPORARY BREEDING DISTRIBUTION — KAUA'I

A map of known contemporary breeding distribution of the BRSP was created, based on data collected from 1 942 human auditory surveys (amounting to 3 712 h of observations) and all automated acoustic sensors. The highest call rates were found along the Na Pali coast and Waimea Canyon, with the highest call rate being 769 calls/h on 13 June 2012 at Nu'alolo Aina (Fig. 4).

Modeled breeding distribution — Kaua'i

Of the seven variables considered in the model, average rainfall, EVI, and slope were the most influential, found in 85% of all models. The relative influence of each predictor to the overall model was estimated and scaled out of 100 (Table 3). Elevation was slightly influential, while aspect x and y and percentage of rock were incorporated in <6% of models each. BRSP presence was predicted in areas of low rainfall, low EVI (low to no vegetation), and slopes >40°. The area under the curve for the final model was 0.95, which was calculated by cross-validation of the data using the *gbm.step* function. Finally, these data were used to model the predicted distribution of the species across Kaua'i (Fig. 5).

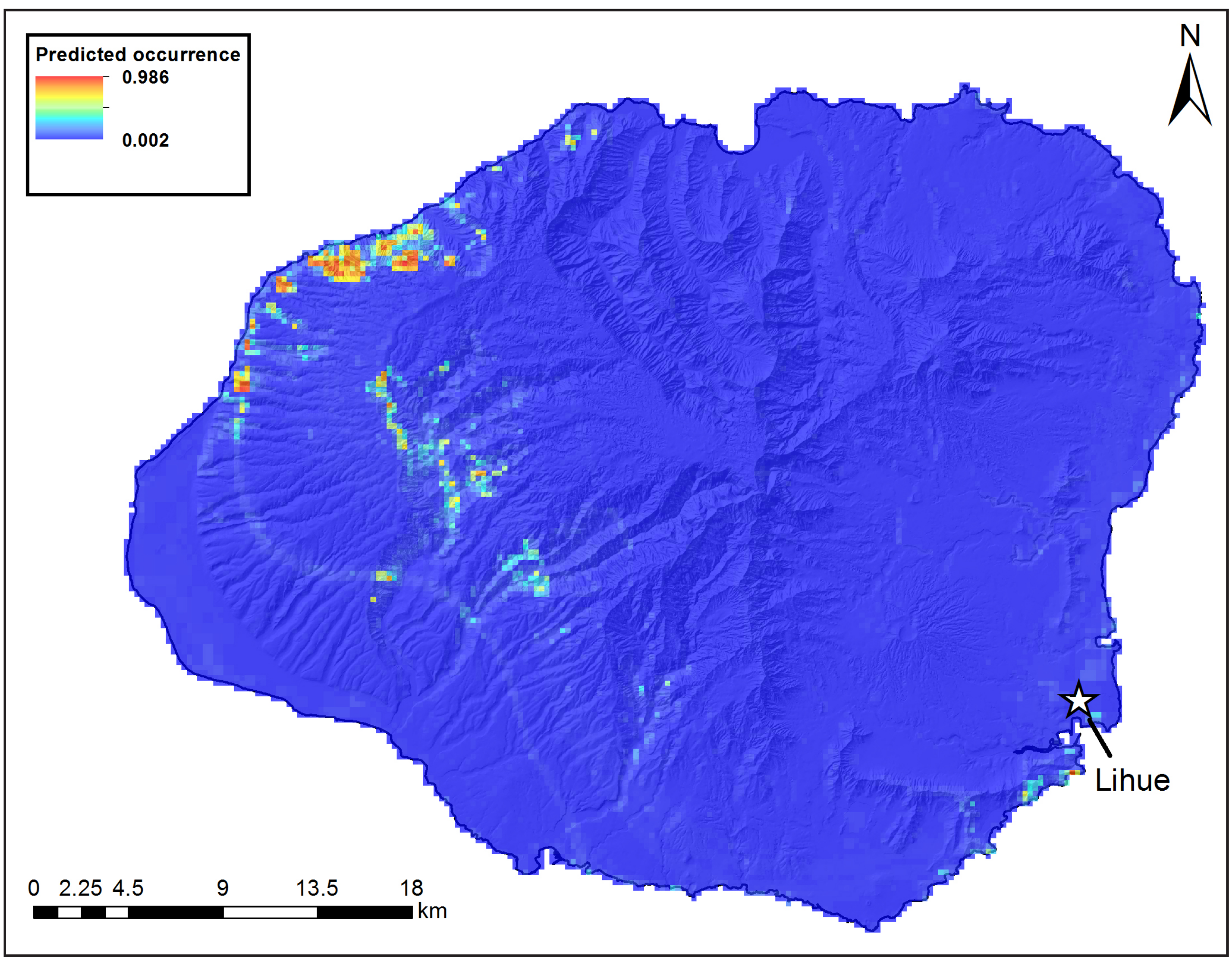

Fig. 5. Predicted distribution of the Band-rumped Storm-petrel on Kaua'i.

Contemporary breeding distribution — Lehua Islet

Maps were created to assess BRSP breeding distribution by considering data from all acoustic sensors deployed on the islet between 2013 and 2015 (n = 19). Records indicated that storm-petrel calling was detected at 31.6% of sites, with the majority of activity on the southeastern slope of the islet (Fig. 6). Human auditory surveys were subsequently conducted in the areas where acoustic sensors detected the highest call rates. Surveyors reported multiple sightings of low flying BRSPs, many of which vocalized constantly as they flew low over the ground.

DISCUSSION

On Kaua'i, BRSPs were found predominantly along the northwestern coast, with concentrations in the narrow valleys of the Na Pali coast as well as the sheer walls of the Waimea Canyon in the southwestern region of the island. Interestingly, small colonies were also found within some of the larger, more vegetated valleys, such as Lumahai and Wainiha, where they were associated with rocky cliff faces. Modeling the distribution of this species indicated an association with such steep, sparsely vegetated cliff faces. On Lehua Islet, the species was mainly concentrated on the southeastern slopes, with very little activity elsewhere. The area where storm-petrels were recorded on Lehua Islet is also very sparsely vegetated and steeply sloping, showing a similarity to preferred habitat on Kaua'i; the distribution of the species on Lehua could also be limited by the presence of introduced Polynesian Rats *Rattus exulans*.

BRSPs were found to be summer breeders on Kaua'i, with no evidence of a winter breeding population. An exclusively summer breeding season is similar to that found for the species in Japan (Monteiro & Furness 1988), but is unlike breeding populations in the Galápagos, where the breeding season is bimodal (Snow & Snow 1966, Harris 1969, Smith & Friesen 2007). On Kaua'i, birds arrive in late May and fledge in October to mid-November. One very early fledgling was listed in SOS records as being found on 11 September 1997, 27 d earlier than any other fledgling in the database; the only other fledgling recorded in that year was found in mid-October. It is possible that this bird was incorrectly identified by SOS staff as a fledgling, or that it was from a very early breeding pair. Whatever the case, it is the only outlier and presumably is not indicative of the normal schedule for the breeding season on Kaua'i.

The current breeding distribution of BRSPs on Kaua'i and Lehua Islet is likely due to a combination of available habitat, constrained by predation pressure from introduced predators. On Kaua'i, the depredated remains of a BRSP were found in 2013 in Nualolo Aina on the Na Pali coast with injuries consistent with Barn Owl *Tyto alba* depredation (Raine, unpubl. data). Indeed, the Barn Owl is a known predator of seabirds on Kaua'i, where it also targets Newell's Shearwater *Puffinus newelli* (Ainley *et al.* 2001), Hawaiian Petrel *Pterodroma sandwichensis* (Raine unpubl. data), Bulwer's Petrel *Bulweria bulwerii*, and Wedge-tailed Shearwater *Ardenna pacifica* (Raine *et al.* 2017). Further evidence of Barn Owls hunting storm-petrels includes the fact that Barn Owls were regularly attracted by broadcasts of storm-petrel calls during banding sessions; Barn Owls were often the first birds to arrive at the banding sites. Barn Owls have also been recorded predating storm-petrels on islands in the Gulf of California (Velarde *et al.* 2007) and off California (Mills 2016).

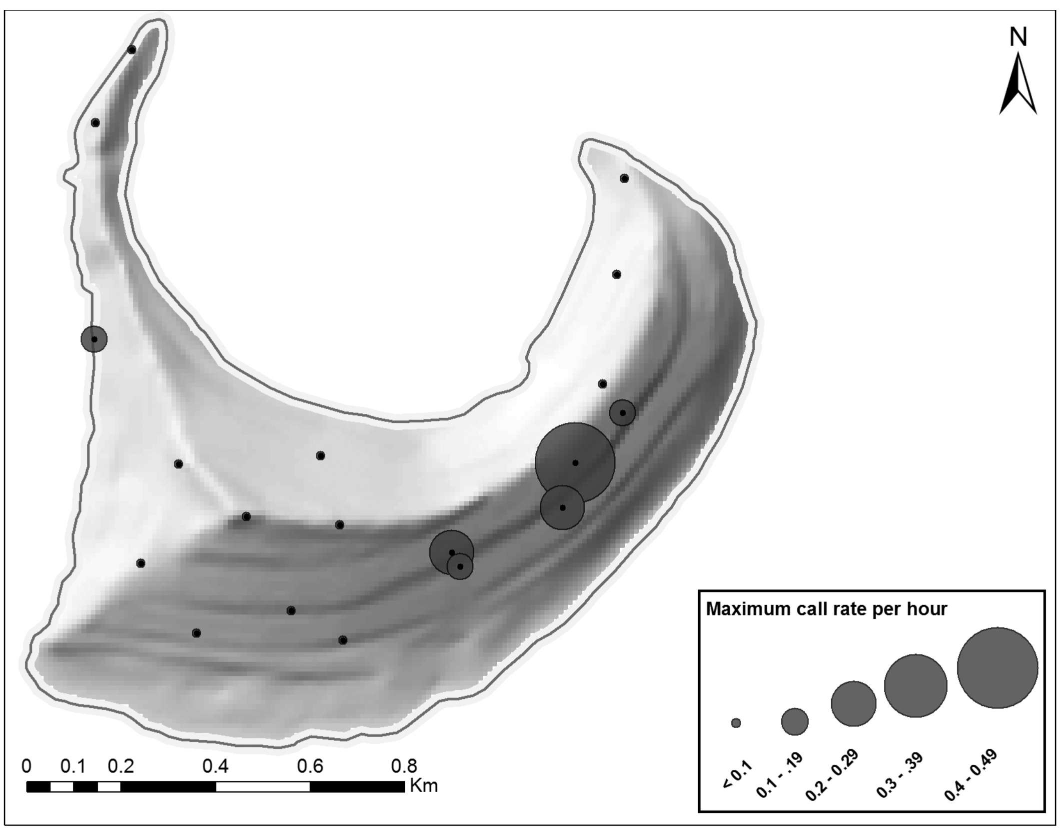

Fig. 6. Maximum call rates of Band-rumped Storm-petrel recorded on automated acoustic recorders (black dots) deployed on Lehua Islet (2013, 2014, and 2015).

Storm-petrels in general are particularly vulnerable to introduced mammalian predators such as Black Rats *Rattus rattus*, Polynesian Rats, and cats *Felis catus* (Rauzon *et al.* 1985, Scott *et al.* 1988, Harrison 1990, Martin *et al.* 2000, Slotterback 2002, Towns *et al.* 2006, Jones *et al.* 2008). On Hawai'i, at a newly discovered BRSP colony at Pohakuloa Training Area, two depredated carcasses were discovered, one of which was thought to be a chick (Galase *et al*. 2016). Cameras monitoring potential breeding sites there recorded rats entering a suspected burrow entrance on multiple occasions, and cat scat was also found within the study area. Throughout the Hawaiian Islands and central Pacific islands, introduced predators are a key threat to all ground-nesting seabirds (Simons 1985, Harrison 1990, Hodges & Nagata 2001, Ainley *et al.* 2001, Rauzon 1985). BRSPs face this same threat, with no known contemporary breeding population occurring in a predator-free habitat.

Light attraction, which seriously affects other seabirds on Kaua'i (Telfer *et al.* 1987, Reed *et al.* 1985, Duffy 2010), also appears to affect BRSPs, although there is a relatively small number of fallout fledglings in the SOS database. This could be due to a number of factors. First, the species is currently concentrated predominantly along northwest coast, but artificial lights are concentrated on the opposite coast (Troy *et al.* 2011). Second, although light attraction among other storm-petrels is well known (e.g., Wiese *et al.* 2001, Montevecchi 2006), this species may be less affected by artificial lights. Lastly, its small size and habit of rapidly looking for hiding places once on the ground could render it less likely to be found by the general public. This could make it an under-reported species within the SOS program.

Determining the breeding phenology and distribution of BRSPs is a key first step in co-ordinating conservation efforts to better protect this species' population on Kaua'i and adjacent Lehua Islet. Controlling introduced avian and mammalian predators in the current core areas of its breeding distribution should be considered a priority, considering how vulnerable the species is to predation. The eradication of rats from Lehua Islet, for example, would remove a key threat from this breeding location, particularly if it were carried out in tandem with ongoing efforts to control Barn Owls on the islet. Adding artificial nest burrows may also help increase breeding success in certain areas, such as Lehua Islet, by increasing available breeding habitat (as has been shown with other *Ocenodroma* species, e.g., McIvery 2016). Undertaking larger-scale studies, similar to what we report herein, on other Hawaiian islands should be considered a priority. Lastly, the uncertainty of the overall genetic composition of *Oceanodroma castro* across its entire Atlantic and Pacific distribution is currently a limiting factor in identifying which populations are in most urgent need of conservation action. If, indeed, there are several unique genetic forms across the current broad distribution of BRSPs, identifying these will help to focus conservation action.

ACKNOWLEDGEMENTS

We would like to acknowledge all of the hard work undertaken over the years by technicians working for the Kaua'i Endangered Seabird Recovery Project (KESRP), which is predominantly carried out in remote and very challenging locations. KESRP is a joint project of the Department of Land and Natural Resources, Division of Forestry and Wildlife (DOFAW), and the Pacific Co-operative Studies Unit (PCSU) of the Research Corporation of the University of Hawaii. We thank all of the staff at DOFAW and PCSU involved in providing project support and assistance, especially David Duffy of PCSU and Sheri Mann and Thomas Ka'iakapu of DOFAW. We would also like to thank the staff working for Conservation Metrics, for their work in isolating the calls of this species. Funding for this work was provided from several sources: the Kaua'i Island Utility Cooperative, SunEdison (formerly First Wind Energy), and multiple State Wildlife Grants provided by the US Fish and Wildlife Service. We extend our thanks to all staff working for these entities who have been involved in processing the funding and facilitating the work. We also thank Tracy Anderson, Maddy Jacobs, and all of the staff at the Save Our Shearwaters project for their dedication to rescuing and rehabilitating threatened and endangered seabirds and other species on Kaua'i. Lastly, we would like to thank the anonymous reviewers and the editor of *Marine Ornithology* (David Ainley), whose comments helped to clarify our paper. All banding undertaken for this paper was carried out under Federal Bird Banding Permit 08487-I.

REFERENCES

AINLEY, D.G., PODOLSKY, R., DEFOREST, L., SPENCER, G. & NUR, N. 2001. The status and population trends of the Newell's shearwater on Kaua'i: insights from modeling. *Studies in Avian Biology* 22: 108-123.

BANKO, W., BANKO, P.C. & DAVID, R.E. 1991. Specimens and probable breeding activity of the band-rumped storm-petrel on Hawaii. *Wilson Bulletin* 1991: 650-655.

BOERSMA, P.D. & GROOM, M.J. 1993. Conservation of storm-petrels in the North Pacific. In: *The status, ecology, and conservation of marine birds of the North Pacific*. Canadian Wildlife Service Special Publication. Ottawa, ON: Canadian Wildlife Service. pp. 70-81.

BOLTON, M. 2007. Playback experiments indicate absence of vocal recognition among temporally and geographically separated populations of Madeiran Storm-petrels *Oceanodroma castro*. *Ibis* 149: 255-263.

BUSTON, P.M. & ELITH, J. 2011. Determinants of reproductive success in dominant pairs of clownfish: A boosted regression tree analysis. *Journal of Animal Ecology* 80: 528-538.

CIRESAN, D., MEIER, U. & SCHMIDHUBER, J. 2012. Multi-column deep neural networks for image classification. In: *2012 IEEE Conference on Computer Vision and Pattern Recognition*. Providence, RI: Institute for Electrical and Electronics Engineers. pp. 3642-3649.

DEL HOYO, J.D., ELLIOTT, A. & SARGATAL, J. 1992. *Handbook of the Birds of the World Vol. 1 — Ostrich to Ducks*. Barcelona, Spain: Lynx Edicions/Birdlife International.

DENG, L., HINTON, G. & KINGSBURY, B. 2013. New types of deep neural network learning for speech recognition and related applications: an overview. In: *2013 IEEE International Conference on Acoustics, Speech and Signal Processing*. Vancouver, BC: Institute for Electrical and Electronics Engineers. pp. 8599-8603.

DUFFY, D.C. 2010. Changing seabird management in Hawai'i: from exploitation through management to restoration. *Waterbirds* 33: 193-207.

ELITH, J. & LEATHWICK, J.R. 2011. Boosted Regression Trees for ecological modeling. 1–22. [Available online at: http://cran.r-project.org/web/packages/dismo/vignettes/brt.pdf. Accessed 7 March 2017]

FRIESEN, V.L., SMITH, A.L., GOMEZ-DIAZ, E., ET AL. 2007. Sympatric speciation by allochrony in a seabird. *Proceedings of the National Academy of Sciences* 104: 18589-18594.

GALASE, N.K., DORATT, R.E., INMAN-NARAHARI, N.V., LACKEY T.M., SCHNELL, L.D. & PESHUT, P.J. 2016. *2015 seabird project technical report: Band-rumped Storm Petrel (*Oceanodroma castro*) colony presence and flight paths at Pohakuloa Training Area, Hawaii*. Pohakuloa, HI: Natural Resources Office.

HARRIS, M.P. 1969. The biology of storm petrels in the Galápagos Islands. *Proceedings of the California Academy of Sciences* 37: 95-166.

HARRISON, C.S. 1990. *Seabirds of Hawaii: Natural History and Conservation.* Cornell, NY: Cornell University Press.

HAWAII HERITAGE PROGRAM. 1992. *Biological database and reconnaissance survey of Kaho'olawe Island including rare plants, animals and natural communities.* Kaho'olawe Island Conveyance Commission Consultant Report No. 6. Honolulu, HI: Hawaii Heritage Program.

HIJMANS, R.J. & ELITH, J. 2012. *Species distribution modeling with R.* [Available online at: https://cran.r-project.org/web/packages/dismo/vignettes/sdm.pdf. Accessed 5 March 2017.]

HODGES, C.S.N. & NAGATA, R.J. 2001. Effects of predator control on the survival and breeding success of the endangered Hawaiian Dark-rumped Petrel. *Studies in Avian Biology* 22: 308-318.

HUETE, A., DIDAN, K., MIURA, T., RODRIGUEZ, E.P., GAO, X. & FERREIRA, L.G. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment* 83: 195-213. doi: 10.1016/S0034-4257(02)00096-2.

JONES, H.P., TERSHY, B.R., ZAVALETA, E.S., CROLL, D.A., KEITT, B.S., FINKELSTEIN, M.E. & HOWALD, G.R. 2008. Severity of the effects of invasive rats on seabirds: a global review. *Conservation Biology* 22: 16-26.

KRIZHEVSKY, A., SUTSKEVER, I. & HINTON, G.E. 2012. ImageNet classification with deep convolutional neural networks. In: JORDAN, M.I., LECUN, Y., & SOLLA, S.A. (Eds.) *Advances in Neural Information Processing Systems: Proceedings of the First 12 Conferences*. Cambridge, MA: The MIT Press. pp. 1097-1105.

MARTIN, J.L., THIBAULT, J.C. & BRETAGNOLLE, V. 2000. Black rats, island characteristics, and colonial nesting birds in the Mediterranean: consequences of an ancient introduction. *Conservation Biology* 14: 1452-1466.

McIVER, W.R., CARTER, H.R., HARVEY, A.L., MAZURKIEWICZ, D.M. & MASON, J.W. 2016. Use of social attraction to restore Ashy Storm-Petrels *Oceanodroma homochroa* at Orizaba Rock, Santa Cruz Island, California. *Marine Ornithology* 44*:* 99-112.

MILLS, K. 2016. Seabirds as part of migratory owl diet on Southeast Farallon Island, California. *Marine Ornithology* 44: 121-126.

MONTEIRO, L.R. & FURNESS, R.W. 1998. Speciation through temporal segregation of Madeiran storm petrel (*Oceanodroma castro*) populations in the Azores?. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 353 (1371): 945-953.

MONTEVECCHI, W.A. 2006. Influences of artificial light on marine birds. In: RICH, C. & LONGCORE, T. (Eds.) *Ecological Consequences of Artificial Night Lighting*. Washington, DC: Island Press. pp. 94-113.

NUNES, M.A. 2000. Madeiran Storm-Petrel (*Oceanodroma castro*) in the Desertas Islands (Madeira archipelago): a new case of two distinct populations breeding annually. *Arquipélago, Life Marine Science* Suppl. 2 (Part A): 175-179.

OLSON, S.L. & JAMES, H.F. 1982. Fossil birds from the Hawaiian Islands: evidence for wholesale extinction by man before Western contact. *Science* 217 (4560): 633-635.

OPPEL, S., HERVIAS, S., OLIVEIRA, N., ET AL. 2014. Estimating population size of a nocturnal burrow-nesting seabird using acoustic monitoring and habitat mapping. *Nature Conservation* 7: 1-13.

PYLE, R.L. & PYLE, P. 2009. *The Birds of the Hawaiian Islands: Occurrence, History, Distribution, and Status.* Honolulu, MI: Bishop Museum.

RAINE, A.F., McFARLAND, B., BOONE, M. & BANFIELD, N. 2017. An updated avifauna of Moku'ae'ae Rock Islet, Kaua'i. *Pacific Science* 71: 67-76.

RAUZON, M.J., HARRISON, C.S. & CONANT, S. 1985. The status of the sooty storm-petrel in Hawaii. *Wilson Bulletin* 97: 390-392.

REED, J.R., SINCOCK, J.L. & HAILMAN, J.P. 1985. Light attraction in endangered procellariiform birds: reduction by shielding upward radiation. *Auk* 102: 377-383.

SCOTT, J.M., KEPLER, C.B., VAN RIPER, C. & FEFER, S.I. 1988. Conservation of Hawaii's vanishing avifauna: Hawaiian birds provide one of the best, and most spectacular, showcases of divergent evolution. *BioScience* 38: 238-253.

SIMONS, T.R. 1985. Biology and behavior of the endangered Hawaiian Dark-rumped Petrel. *Condor* 87: 229-245.

SLOTTERBACK, J.W. 2002. Band-rumped Storm-Petrel (*Oceanodroma castro*) and Tristram's Storm-Petrel (*Oceanodroma tristrami*). In: POOLE, A. & GILL, F. (Eds.) *The Birds of North America,* No. 673. Philadelphia, PA: The Academy of Natural Sciences.

SMITH, A.L., MONTEIRO, L., HASEGAWA, O. & FRIESEN, V.L. 2007. Global phylogeography of the band-rumped storm-petrel (*Oceanodroma castro*; Procellariiformes: Hydrobatidae). *Molecular Phylogenetics and Evolution* 43: 755-773.

SMITH, A.L. & FRIESEN, V.L. 2007. Differentiation of sympatric populations of the band-rumped storm-petrel in the Galapagos Islands: an examination of genetics, morphology, and vocalizations. *Molecular Ecology* 16: 1593-1603.

SNOW, D.W. & SNOW, B.K. 1966. The breeding season of the Madeiran Storm Petrel *Oceanodroma castro* in the Galapagos. *Ibis* 108: 283-284.

SPEAR, L.B., & AINLEY, D.G. 2007. Storm-petrels of the eastern Pacific Ocean: species assembly and diversity along marine habitat gradients. *Ornithological Monographs*, No. 62, iii-77.

TELFER, T.C., SINCOCK, J.L., BYRD, G.V. & REED, J.R. 1987. Attraction of Hawaiian seabirds to lights: conservation efforts and effects of moon phase. *Wildlife Society Bulletin (1973–2006)* 15: 406-413.

TOWNS, D.R., ATKINSON, I.A. & DAUGHERTY, C.H. 2006. Have the harmful effects of introduced rats on islands been exaggerated?. *Biological invasions* 8: 863-891.

TROY, J.R., HOLMES, N.D. & GREEN, M.C. 2011. Modeling artificial light viewed by fledgling seabirds. *Ecosphere* 2: 1-13.

US FISH AND WILDLIFE SERVICE (USFWS). 2016. *Endangered and threatened wildlife and plants: endangered status for 49 species from the Hawaiian islands*. USFWS, US Federal Register Docket No. FWS-R1-ES-2015-0125;4500030113. [Available online at: https://www.federalregister.gov/documents/2016/09/30/2016-23112/endangered-and-threatened-wildlife-and-plants-endangered-status-for-49-species-from-the-hawaiian. Accessed 5 March 2017.]

VANDERWERF, E.A., WOOD, K.R., SWENSON, C., LEGRANDE, M., EIJZENGA, H. & WALKER, R.L. 2007. Avifauna of Lehua Islet, Hawai'i: conservation value and management needs. *Pacific Science* 61: 39-52.

VELARDE, E., AVILA-FLORES, R. & MEDELLIN, R.A. 2007. Endemic and introduced vertebrates in the diet of the barn owl (*Tyto alba*) on two islands in the Gulf of California, Mexico. *Southwestern Naturalist* 52: 284-290.

WIESE, F.K., MONTEVECCHI, W.A., DAVOREN, G.K., HUETTMANN, F., DIAMOND, A.W. & LINKE, J. 2001. Seabirds at risk around offshore oil platforms in the North-west Atlantic. *Marine Pollution Bulletin* 42: 1285-1290.

WOOD, K.R., BOYNTON, D., VANDERWERF, E., ET AL. 2002. *The distribution and abundance of the Band-rumped Storm-Petrel (*Oceanodroma castro*): A preliminary survey on Kaua'i, Hawai'i*. Report to the US Fish and Wildlife Service, Pacific Islands Office, Honolulu, Hawai'i: US Fish and Wildlife Service.