THE CONDOR
Ornithological Applications
AmericanOrnithology.org

Volume 121, 2019, pp. 1–7
DOI: 10.1093/condor/duy004

COMMENTARY

Evidence of Newell's Shearwaters and Hawaiian Petrels on Oahu, Hawaii

Lindsay C. Young,[1*] Eric A. VanderWerf,[1] Matthew McKown,[2] Paige Roberts,[2] Jeff Schlueter,[2] Adam Vorsino,[3] and David Sischo[4]

[1] Pacific Rim Conservation, Honolulu, Hawaii, USA
[2] Conservation Metrics, Santa Cruz, California, USA
[3] U.S. Fish and Wildlife Service, Pacific Islands Office, Honolulu, Hawaii, USA
[4] Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife, Honolulu, Hawaii, USA
* Corresponding author: lindsay@pacificrimconservation.org

Submitted April 11, 2018; Accepted September 11, 2018; Published January 22, 2019

ABSTRACT
Hawaii's only 2 endemic seabirds, Newell's Shearwater (*Puffinus auricularis newelli*) and Hawaiian Petrel (*Pterodroma sandwichensis*), are listed under the United States Endangered Species Act. Threats to both species include light attraction and fallout, collisions with power lines and other structures, predation by invasive animals, and habitat degradation. Both species were assumed to be extirpated from the island of Oahu despite limited survey effort. We used survey data from Kauai (both species) and Maui (Hawaiian Petrel only) to model suitable habitat and light conditions. We then projected this model onto Oahu to identify potential survey sites. From April to September of 2016–2017, we deployed automated acoustic recording units at 13 potentially suitable sites across Oahu. We detected Newell's Shearwaters at 2 sites; one on the leeward slopes of Mount Kaala in the Waianae Mountains and another at Poamoho in the Koolau Mountains. We detected Hawaiian Petrels at one location on the windward slope of Mount Kaala. All 3 sites were in nearly intact native forest with steep slopes. The frequency of detections at these sites suggests that both species are regularly prospecting on Oahu and potentially could be breeding there. If they are breeding, these individuals could represent missing links in the population connectivity of both species among islands. Protecting any remnant breeding populations would be of high conservation value given their recent population declines.

Keywords: acoustic monitoring, habitat suitability, Hawaiian Petrel, Hawaiian seabirds, Newell's Shearwater, Oahu

Evidencia de Puffinus auricularis newelli y Pterodroma sandwichensis en Oahu, Hawái

RESUMEN
Las dos únicas especies de aves marinas endémicas de Hawái, *Puffinus auricularis newelli* y *Pterodroma sandwichensis*, están incluidas en la Ley de Especies en Peligro de Estados Unidos. Las amenazas para ambas especies incluyen atracción a la luz y caída, colisiones con líneas eléctricas y otras estructuras, depredación por animales invasores y degradación de hábitat. Se asumía que ambas especies habían sido extirpadas de la isla de Oahu, a pesar de un esfuerzo limitado de muestreo. Usamos datos de monitoreo de Kauai (para ambas especies) y de Maui (solo para *P. sandwichensis*) para modelar el hábitat adecuado y las condiciones de luz. Luego, proyectamos este modelo sobre Oahu para identificar sitios potenciales de muestreo. De abril a septiembre de 2016–2017, emplazamos unidades de grabación acústica automática en 13 sitios potencialmente adecuados a lo largo de Oahu. Detectamos la presencia de *Puffinus auricularis newelli* en dos sitios; uno en las laderas de sotavento de Monte Kaala en las Montañas Waianae, y otro en Poamoho en las Montañas Koolau. Detectamos la presencia de *Pterodroma sandwichensis* en un sitio, en las laderas de barlovento de Monte Kaala. Los tres sitios estuvieron en bosques nativos casi intactos con laderas abruptas. La frecuencia de las detecciones en estos sitios sugiere que ambas especies están periódicamente presentes en Oahu y que podrían potencialmente criar allí. Si estuviesen reproduciéndose allí, estos individuos podrían representar estabones perdidos de la conectividad poblacional entre islas de ambas especies. La protección de cualquiera de las poblaciones reproductivas remanentes sería de alto valor de conservación dadas sus disminuciones poblacionales recientes.

Palabras clave: aves marinas de Hawái, hábitat adecuado, monitoreo acústico, Oahu, *Pterodroma sandwichensis*, *Puffinus auricularis newelli*

INTRODUCTION

Hawaii's only 2 endemic seabirds, Newell's Shearwater (*Puffinus auricularis newelli*) and Hawaiian Petrel (*Pterodroma sandwichensis*), are listed as threatened and endangered, respectively, under the United States Endangered Species Act (ESA; USFWS 1983). Threats to both species include light attraction and fallout, collisions with power lines and other structures, predation by invasive animals, and habitat degradation (Ainley et al. 1997, Simons and Hodges 1998, Ainley et al. 2001). These pressures have resulted in serious declines in both species over the last 20 yr, particularly for shearwaters (Raine et al. 2017). The most recent population estimates are 20,550 for Newell's Shearwaters and 11,900 for Hawaiian Petrels (Pyle and Pyle 2017). On Kauai, ornithological radar surveys, combined with returns of downed birds to the Save Our Shearwaters program, show an apparent decline of 94% from 1993 to 2013 for shearwaters and 78% for petrels (Raine et al. 2017). The population declines for shearwaters were corroborated by changes in at-sea population estimates, with approximately 84,000 individuals estimated based on data collected between 1984 and 1993 (Spear et al. 1995).

Both species are loosely colonial and nest in burrows, crevices, or under vegetation in at least 2 habitat types: middle to high elevation (160–1,200 m), wet native montane forest on steep slopes dominated by ohia trees (*Metrosideros polymorpha*) with uluhe fern (*Dicranopteris linearis*) understory (Ainley et al. 1997). In addition, petrels are known to breed in open, rocky subalpine habitat at high elevation (>2,000 m; Ainley et al. 1997). Historically, both species were found from sea level to the mountain tops on all the main Hawaiian Islands, and they were among the most abundant seabirds in Hawaii (Olson and James 1982). Their current breeding ranges have been greatly constricted in area and habitat diversity compared to the historical breeding range because of habitat loss and predation by nonnative mammals. Virtually all extant breeding colonies are located in areas that are inaccessible to mammalian predators, such as steep cliffs, or that have low predator density, such as open lava fields at high elevation. In addition, attraction of fledglings to artificial light sources and subsequent grounding in urban areas is a significant cause of juvenile mortality (Ainley et al. 1997, Troy et al. 2011). Over time, reduced recruitment resulting from fallout of juveniles could cause colonies to dwindle in areas with greater exposure to artificial light.

More than 90% of the extant shearwater population is found on Kauai, with scattered colonies on Maui and Hawaii (Ainley et al. 1997). While the population size of petrels is thought to be smaller, they are more widely distributed in similar-sized colonies on Kauai, Maui, Lanai, and Hawaii, thus providing some level of protection against catastrophes and stochastic forces. For both species, identifying and protecting colonies on other islands is one of the most important actions to safeguard against natural disasters (Holmes et al. 2015). Both species were historically known from Oahu but were thought to have been extirpated from the island prior to European contact in 1778, although dozens of grounded birds have been recovered from around the island (Pyle and Pyle 2017). No systematic, targeted surveys have been done for montane-nesting seabirds on Oahu, and thus information on their status and potential distribution on the island is lacking. If either Newell's Shearwaters or Hawaiian Petrels are breeding on Oahu, those populations would a represent missing link in the population connectivity of these species among islands, and thus protecting any remnant populations would be of high conservation value (Welch et al. 2012).

The purposes of this study were to (1) review historical records of Newell's Shearwater and Hawaiian Petrel sightings on Oahu to search for geographic patterns of occurrence, (2) use models of habitat suitability and light pollution to indicate areas most likely to support remnant breeding populations, and (3) conduct island-wide auditory surveys across potentially suitable habitat.

METHODS

We used 3 methods to identify and survey locations on Oahu where Hawaiian Petrels and Newell's Shearwaters were most likely to occur. First, we searched for historical records of petrels and shearwaters on Oahu by doing an extensive literature search, conducting interviews with local biologists, and by searching the database of bird records at the Bernice Pauahi Bishop Museum (BPBM; Pyle and Pyle 2017). Second, we conducted a habitat suitability and light modeling exercise to prioritize locations for surveying. Finally, we deployed automated acoustic recording units (song meters) to survey for both species in locations identified by the model as most suitable.

Habitat Modeling

We developed habitat suitability models for Newell's Shearwater and Hawaiian Petrel using presence-only data acquired from auditory surveys, nesting site location data, and expert opinion polygons. The data sets included 993 locations for Newell's Shearwater on Kauai and 2,545 locations for Hawaiian Petrel on Kauai and Maui. If survey points overlapped, only a single point per locality was used. Auditory surveys for both species were conducted by the Kauai Endangered Seabird Recovery Project (KESRP) from 2006 to 2012. The nest site location data was collected during surveys from the 1950s to 2008 by KESRP on Kauai and by the National Park Service at Haleakala National Park on Maui.

To develop the habitat suitability model for each species from these presence locations, we selected a subset of variables from a set of 24 abiotic environmental variables using a selection procedure that attempts to remove uninformative or correlated variables (Vorsino et al. 2014, Vorsino 2016). Five variables were selected that best described the distribution of both species (isothermality, precipitation seasonality, slope, topographic roughness index, and wind at 50 m elevation).

Using the selected variables and presence locations, we developed the habitat suitability model for each species by combining 2 commonly used presence-only machine learning methods, MAXENT (Phillips et al. 2006) and Gradient Boosting Model (Friedman 2001). Each projection from MAXENT and the Gradient Boosting Model was then validated using a subset of the species presence data to define the Area Under the Curve (AUC), KAPPA, and True Skill Statistic (TSS). An overall habitat assessment was developed from both methods that best described the relationship of shearwater and petrel locations to the various topographic and climatic variables used in the assessment. A weighted means ensemble of each validation metric definitive of both modeling approaches was then used to infer habitat suitability, as projected onto Oahu.

Overlap of artificial light with otherwise suitable shearwater and petrel habitat is an important habitat modifier that may limit the current breeding distribution of both species. As such, it is an essential variable to include when determining potential suitability of a site. As outlined in Vorsino (2016), we developed a threshold from which light was projected into unlit areas. This threshold was developed by extracting light intensity metrics for all seabird auditory detections from the 15 arc-second Visible Infrared Imaging Radiometer Suite (NOAA 2018). The threshold from which light impact was projected was defined using the 3rd quartile of a boxplot developed from the extracted light intensity data. This threshold seemed to best exemplify seabird sightings, maximized high-intensity light source areas, and minimized indirect sky glow (Chalkias et al. 2006). A viewshed was then developed from the periphery of this threshold across a 10 m digital elevation model after elevating them by 100 m (as conducted by Troy et al. 2011) to account for possible light detection during fledgling flight and projected onto a 0–100% visibility scale. The areas defined as lit (i.e. below the 3rd quartile of light intensity) were classified as 100% visible, and thus do not vary in intensity.

Song Meter Programming and Deployment Locations

Remote acoustic monitoring has been found to be an effective technique for detecting the presence of rare, nocturnal seabirds like Hawaiian Petrels and Newell's Shearwaters (Buxton and Jones 2012). This method takes advantage of the social behavior and frequent vocalizations that occur at breeding colonies. To search for these cryptic species, we deployed automated acoustic recording devices (Wildlife Acoustics SM4 and SM2 song meters) at 16 locations on Oahu. Recorders at 3 locations failed to make recordings, resulting in 13 locations with data (Figure 1). We chose locations where Newell's Shearwaters or Hawaiian Petrels had been previously recorded on the island, or where suitable habitat existed based on modeling outcomes. We deployed song meters at 3 locations in 2016 and 15 locations in 2017 for a total of 13 unique survey points (2 of the locations surveyed in 2016 were repeated in 2017). Five sites were in the Koolau Range on the eastern side of Oahu and 8 were in the Waianae Range on the western side of the island. Of the 13 locations, we accessed 6 by helicopter and 7 by hiking. We deployed song meters from April to June and retrieved them in September–November each year to correspond with the breeding season of both species. We visited every 1–3 mo during the deployment period to retrieve data and service the units.

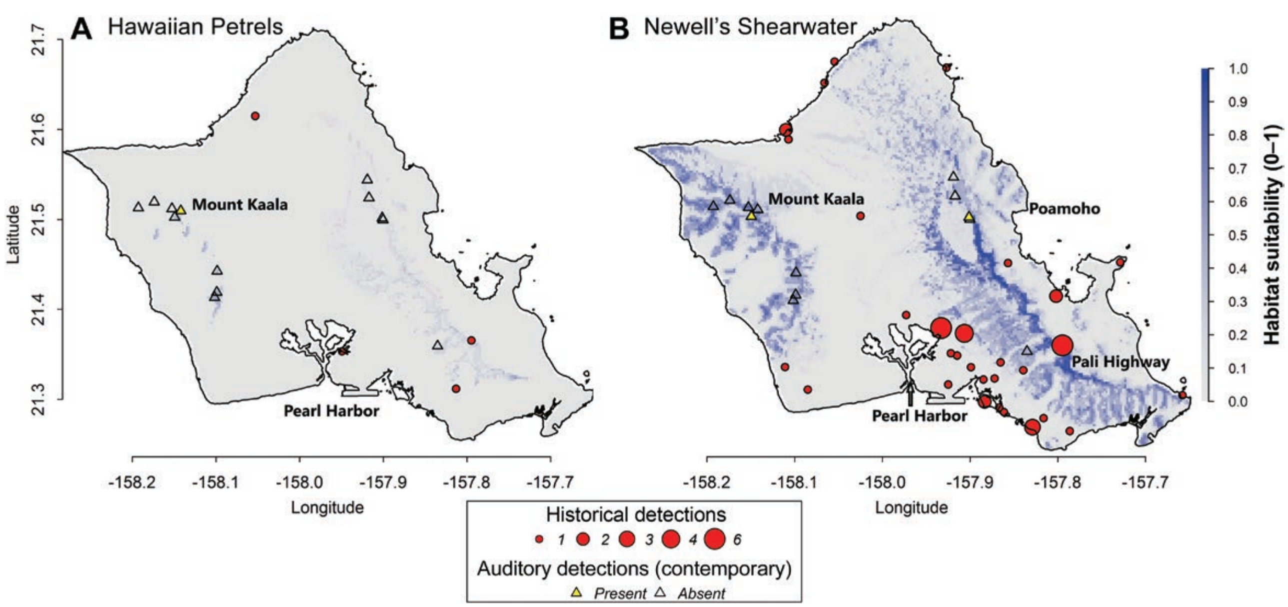

FIGURE 1. Historical and current observations of (**A**) Hawaiian Petrels and (**B**) Newell's Shearwaters overlaid with projected suitable habitat on Oahu.

Each song meter was programmed to record data each day from sunset to 2 hr after sunset and for 1.5 hr starting 2 hr before sunrise. These correspond to the peak calling periods when birds typically are either flying into their burrows after sunset or departing their burrows just before sunrise. For both species, more than 95% of vocalizations occur from sunset to 2 hr post sunset and from 2 hr to 30 min before sunrise (Ainley et al. 1997, Simons and Hodges 1998). To increase the likelihood of detecting birds, the song meters also were programmed to record for 1 min of every 5-min block from sunset to 4 hr before sunrise to capture sporadic calls throughout the night. The total recording time was 5.2 hr per night per unit.

Data Analysis

Automated acoustic analysis of all field recordings was carried out using classifications based on the Deep Neural Networks machine learning technique (Schmidhuber 2015). This approach detects sounds on field recordings that have spectro-temporal properties similar to those measured from signals produced by target species and then splits field recordings into 2-second clips and extracts measurements of 10 spectro-temporal features typically found in animal sounds. A Deep Neural Network classification model was then trained for each species using training and cross-validation datasets containing examples of positive sounds (vocalizations from Newell's Shearwaters and Hawaiian Petrels) and a representative example of "negative" sound clips (i.e. sound clips from the soundscape at all survey sites that do not contain the species of interest). Each classification model returns a probability that a given 2-second window of field recordings contains a sound produced by the target species. All events flagged by the automated classification model were manually reviewed to confirm correctly identified Hawaiian Petrel or Newell's Shearwater calls.

RESULTS

Historical Records

For Hawaiian Petrels, the records of historical observations on Oahu were sparse: since 1991 at least 10 grounded live birds were turned in to Sea Life Park for rehabilitation (Pyle and Pyle 2017). Four more petrels were found dead; two were close to Honolulu Harbor, one in Manoa Valley in Honolulu, and one at the Kawailoa Wind Farm (Figure 1).

For Newell's Shearwaters, there were at least 45 records of birds found throughout the island, with concentrations southwest of the Pali Highway Tunnel in upper Nuuanu Valley, where strong trade winds force them down, and on the northeast side of Pearl Harbor (Figure 1; Banko 1980). The cause of the relatively large number of observations from Pearl Harbor is unknown. Newell's Shearwater observations from the Pali Highway included 5 birds in 1967 (Sincock and Swedberg 1969), 3 birds from 1971–1975 (Banko 1980, Conant 1980), and 2 in 2008 (Pyle and Pyle 2017). Shallenberger (1976) also reported seeing Newell's Shearwaters flying at night over the Pali Highway in the early 1970s. In 2006, a resident in Kalihi Valley recorded calls of Newell's Shearwaters passing over his house regularly (E. VanderWerf personal observation). Of the 36 birds turned in to the Sea Life Park for rehabilitation from 1990 to 2003, approximately one-third died, and the rest were banded and released alive (Pyle and Pyle 2017).

Habitat Suitability Analysis

Habitat modeling results indicated that more suitable habitat was present on Oahu for Newell's Shearwaters than for Hawaiian Petrels and that suitable habitat is associated with upper-elevation forest (Figure 1). As all models showed relatively equivalent results, only the KAPPA model is shown. All AUC, KAPPA, and TSS statistics were indicative of an informative projection (i.e. on average greater than 0.85 for AUC [values ranging from 0 to 1.0] and greater than 0.5 and 0.5 for Maxent and GBM [values range from −1.0 to 1.0]; Allouche et al. 2006). As the interest was primarily in habitat suitability, and not necessarily in presence/absence categorization, the plots are projected without a thresholding metric. As characterized in Vorsino (2016), the threshold from which light was projected onto the islands was defined as 0.2234 nano-Watts/(sr*cm^2). From this threshold, and using the Oahu based VIIRS and DEM maps, the light viewshed was projected and plotted with both species' presence localities (Figure 2).

Auditory Detections of Newell's Shearwaters and Hawaiian Petrels

We made 320.04 hr of recordings on 220 nights at 3 sites in 2016 and 4,730.68 hr of recordings on 829 nights at 10 sites in 2017. Recording time varied at each site as a result of deployment dates (which were limited by helicopter schedules and weather), and in some cases song meters malfunctioned during the deployment period, resulting in partial recordings.

We detected Newell's Shearwater calls at 2 sites, one on the leeward slope of Mount Kaala at 1,100 m elevation in the Waianae Mountains, and another at Poamoho in the Koolau Mountains at 650 m elevation (Table 1). All calls detected at the Kaala Natural Area Reserve (NAR) site were in May and June, while calls at Poamoho were detected in September. Most calls were detected within a 3-hr period before sunrise, except one night when calls were detected 99 min after sunset at Poamoho.

We detected Hawaiian Petrel calls at one site, Lower Kaala NAR, on multiple nights in May and July 2017 (Table 1). Although the first calls were detected just before

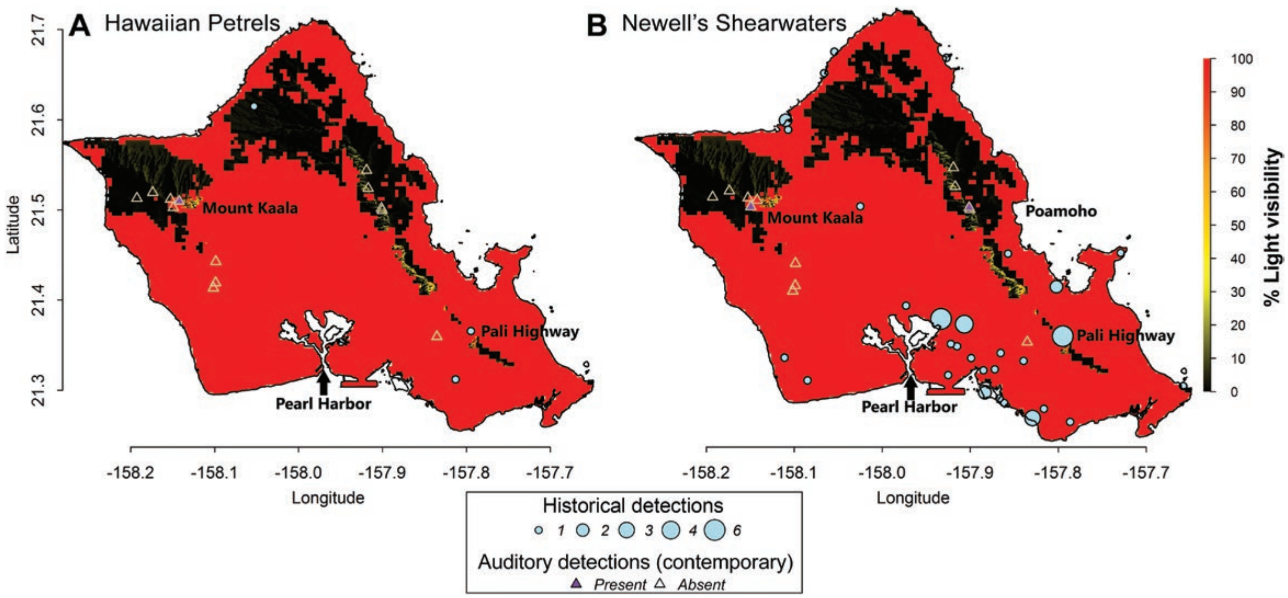

FIGURE 2. Historical and current observations of (**A**) Hawaiian Petrels and (**B**) Newell's Shearwaters overlaid with percentage light visibility.

TABLE 1. Summary of Newell's Shearwater and Hawaiian Petrel calls detected on Oahu in 2017. Minutes from sunrise contains the range of times over which calls were detected on each night. Moon illumination is the percent of the lunar face illuminated on each night.

Species	Site	Date	Time	Number of calls	Minutes from sunrise	Moon illumination
Shearwater	Kaala NAR	May 6, 2017	04:40	1	−78	0.83
Shearwater	Kaala NAR	May 8, 2017	04:43 to 04:49	4	−74 to −68	0.95
Shearwater	Kaala NAR	Jun 3, 2017	04:07 to 04:15	3	−102 to −94	0.71
Shearwater	Kaala NAR	Jun 5, 2017	04:40 & 04:44	2	−69 and −65	0.87
Shearwater	Kaala NAR	Jun 14, 2017	03:12 & 03:17	2	−157 and −152	0.79
Shearwater	Poamoho[a]	Sep 1, 2017	04:32 to 04:39	5	−103 to −96	0.79
Shearwater	Poamoho	Sep 15, 2017	20:13	1	−608	0.18
Shearwater	Poamoho	Sep 22, 2017	04:10	1	−131	0.06
Petrel	Lower Kaala	May 5, 2017	20:42	2	+103	0.81
Petrel	Lower Kaala	May 6, 2017	20:52 to 21:34	4	+112 to +154	0.88
Petrel	Lower Kaala	May 7, 2017	20:16 to 21:15	6	+76 to +135	0.94
Petrel	Lower Kaala	May 17, 2017	20:02 & 20:12	2	+58 to +68	0.58
Petrel	Lower Kaala	May 26, 2017	19:56 to 21:05	18	+48 to +117	0.03
Petrel	Lower Kaala	Jul 21, 2017	20:05 to 22:30	15	+50 to +195	0.02
Petrel	Lower Kaala	Jul 22, 2017	19:49 to 20:17	8	+34 to +62	0.00

[a] This site was not monitored before August 16, 2017, due to sensor failure

the full moon on May 10, subsequent calls were detected during varying moon illuminations; all calls were detected within a 4-hr period after sunset. The site where Hawaiian Petrels were detected was at 1,100 m elevation on the windward slope of Mount Kaala, 1,500 m away from the site of Newell's Shearwater detections. All 3 sites were in largely intact native forest with steep slopes.

DISCUSSION

Habitat modeling results indicated that more suitable habitat was present on Oahu for Newell's Shearwater than for Hawaiian Petrel, which corresponded to higher numbers of both historical and contemporary sightings of shearwaters. It is unclear whether the difference in the amount of apparently suitable habitat is a function of available model parameters (i.e. only reflecting their extant range rather than full historical range), or true habitat availability. Both species, but particularly petrels, once occurred in high densities in coastal lowlands of Oahu (Olson and James 1982). These locations were not represented in the model parameters, which relied solely on extant sightings from nesting locations on other islands. Historical sightings of both species appeared to be correlated more with high light intensity (100% of observations) than with suitable breeding habitat. Given the highly vagile nature of both species, it is likely that birds nesting anywhere on the island could be attracted to lights, or fallout, at any location on the island. Thus their presence, particularly in urban areas, does not necessarily serve as a good indicator of potential breeding in that location.

We detected petrels at one site and shearwaters at two sites where they could potentially be breeding on Oahu. These detections in montane areas on Oahu were unexpected because both species were believed to have been extirpated as breeders from the island prior to the arrival of European explorers in 1778 (Olson and James 1982, Welch et al. 2012). Individuals of both species that have been found on Oahu since then, often grounded in low-elevation urban or suburban areas, are assumed to have been disoriented vagrants from other islands. These detections do not provide evidence that either species is breeding on the island, which might be indicated by regular acoustic activity across the entire breeding season, but the repeated detections at Mount Kaala over several months in 2 yr demonstrate that site is visited regularly by these species. The birds we detected could be the last survivors of remnant breeding populations on Oahu, or they could be young birds from other islands that are prospecting for mates and breeding sites.

Although it was surprising that we detected these species at all, the locations where we detected them were not unexpected given the distribution of historical observations of downed birds moving between breeding sites and at-sea foraging areas and suitable nesting habitat indicated by modeling. The areas on all sides of Mount Kaala and Poamoho are protected as Hawaii State natural area reserves or forest reserves, and they contain some of the least disturbed native forest habitat on the island. Although predators including feral cats, mongooses, and rats are undoubtedly present in these areas, the steep, nearly vertical, slopes present in portions of these areas could provide nest sites that are relatively safe from these predators. Both areas also are among the darkest on Oahu, with little visible light pollution that can attract and confuse birds as they commute to and from the mountains. The small number of Newell's Shearwater calls at the Poamoho site on the other side of Oahu is also intriguing. Several biologists have reported Newell's Shearwater calls in Kualoa Valley and on the ridges in that area over the last 20 yr (D. Duffy personal communication), possibly representing birds transiting to a remnant colony at Poamoho.

Calls of petrels at the Lower Kaala NAR site were detected despite the presence of a constant low-frequency, man-made sound with a frequency (478–550 Hz) that almost completely masked the first, tonal portion of Hawaiian Petrel calls. We believe the sound was made by a satellite communication facility located about 200 m from the survey site. Petrels and other procellariform seabirds can be attracted to a variety of sounds, including recordings of their calls and even human voices (Tennyson and Taylor 1990, Podolsky and Kress 1992, Lawrence et al. 2008). It is possible that the noise from the radar station, which is similar to a portion of their call, is attracting Hawaiian Petrels to the site.

For Newell's Shearwaters, the larger number of grounded birds that have been found island-wide since the 1950s, especially in the proximity of the Pali Highway tunnel, has caused speculation that a breeding colony may persist in the Koolau Mountains near Honolulu (Pyle and Pyle 2017). A second concentration of historical sightings existed at Pearl Harbor, a highly urban, well-lit area around a military installation. However, when the locations of downed birds was overlaid with light sources and suitable habitat, the association with light appears to be stronger than with habitat (Figure 2). The song meter deployed in this region in 2016 (which was also near the location where Newell's Shearwater calling was heard in 2006) did not detect any Newell's Shearwaters or Hawaiian Petrels. It is not out of the question that birds may exist in high-quality habitat in this region, as evidenced by the Poamoho detection farther north, but the presence of so many lights and predators makes their persistence in the mountains above Honolulu unlikely.

ACKNOWLEDGMENTS

We thank C. Miller and the Hawaii Division of Forestry and Wildlife, and the U.S. Fish and Wildlife Service Oahu Forest National Wildlife Refuge for permits and logistical support. In particular, we thank the Oahu Army Natural Resources Program and Matthew Burt for loaning this project 10 SM2 song meters, and providing access and logistical support to several of the study sites. We thank the Kauai Endangered Seabird Recovery Project for providing seabird habitat information to contribute to the modeling exercise, and all reviewers for helping to improve the manuscript.

Funding statement: We thank the National Fish and Wildlife Foundation and the U.S. Fish and Wildlife Service for funding this effort.

Ethics statement: This research followed all necessary state and federal guidelines for work in natural areas and on listed seabird species.

Author contributions: LY and EV conceived the idea, design, experiment (supervised research, formulated question or hypothesis); LY, EV, and DS collected data; LY, EV, MM, AV wrote the paper; LY, EV, AV, MM developed or designed methods; LY, PR, JS, MM, AS analyzed the data; DS contributed substantial resources in the form of helicopter time.

LITERATURE CITED

Ainley, D. G., T. C. Telfer, and M. H. Reynolds (1997). Townsend's and Newell's shearwater (*Puffinus auricularis*). In The Birds of North America 297 (A. Poole and F. Gill, Editors). Academy of Natural Sciences, Philadelphia, PA, USA, and American Ornithologists' Union, Washington, DC, USA.

Ainley, D. G., R. Podolsky, L. de Forest, G. Spencer, and N. Nur (2001). The status and population trends of the Newell's Shearwater on Kauai: Insights from modeling. In Evolution, Ecology, Conservation, and Management of Hawaiian Birds: A Vanishing Avifauna (J. M. Scott, S. Conant, and C. Van Riper III, Editors). Studies in Avian Biology 22:108–123.

Allouche, O., A. Tsoar, and R. Kadmon (2006). Assessing the accuracy of species distribution models: Prevalence, KAPPA and the true skill statistic (TSS). Journal of Applied Ecology 43:1223–1232.

Banko, W. E. (1980). Part I. Population histories—species accounts. Sea birds: Newell's Shearwater ('A'o). CPSU/UH Avian History Report 5B: History of Endemic Hawaiian Birds. Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, Honolulu, HI, USA.

Buxton, R. T., and I. L. Jones (2012). Measuring nocturnal seabird activity and status using acoustic recording devices: applications for island restoration. Journal of Field Ornithology 83:47–60.

Chalkias, C., M. Petrakis, B. Psiloglou, and M. Lianou (2006). Modelling of light pollution in suburban areas using remotely sensed imagery and GIS. Journal of Environmental Management 79:57–63.

Conant, S. (1980). Recent records of the 'Ua'u (Dark-rumped Petrel) and the 'A'o (Newell's Shearwater) in Hawaii. 'Elepaio 41:11–13.

Friedman, J. H. (2001). Greedy function approximation: A gradient boosting machine. Annals of Statistics 29:1189–1232.

Holmes, N., H. Freifeld, F. Duvall, A. Raine, M. Laut, J. Penniman, D. Hu, and C. Bailey (2015). Newell's Shearwater and Hawaiian Petrel recovery: A five-year action plan. U.S. Fish and Wildlife Service, Honolulu, HI, USA. http://kauaiseabirdhcp.com/mt-content/uploads/2016/05/nesh_hape_banp_action_plan-final_usfws-2015-11-13.pdf

Lawrence, H. A., C. D. Millar, G. A. Taylor, L. D. Macdonald, and D. M. Lambert (2008). Excess of unpaired males in one of the world's most endangered seabirds, the Chatham Island Taiko *Pterodroma magentae*. Journal of Avian Biology 39:359–363.

[NOAA] National Oceanic and Atmospheric Administration (2018). VIIRS cloud free composite. National Geophysical Data Center Earth Observation Group. http://www.ngdc.noaa.gov/dmsp/.

Olson, S. L., and H. F. James (1982). Prodromus of the fossil avifauna of the Hawaiian Islands. Smithsonian Contributions to Zoology 365:1–59.

Phillips, S. J., R. P. Anderson, and R. E. Schapire (2006). Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231–259.

Podolsky, R., and S. W. Kress (1992). Attraction of the endangered Dark-rumped Petrel to recorded vocalizations in the Galapagos Islands. The Condor 94:448–453.

Pyle, R. L., and P. Pyle (2017). The Birds of the Hawaiian Islands: Occurrence, History, Distribution, and Status. B.P. Bishop Museum, Honolulu, HI, USA. http://hbs.bishopmuseum.org/birds/rlp-monograph/

Raine, A. F., N. D. Holmes, M. Travers, B. A. Cooper, and R. H. Day (2017). Declining trends of Hawaiian Petrel and Newell's Shearwater on the island of Kauai, Hawaii, USA. The Condor: Ornithological Applications 119:405–415.

Schmidhuber, J. (2015). Deep learning in neural networks: An overview. Neural Networks 61:85–117.

Shallenberger, R. J. (1976). Avifauna: Survey of North Halawa Valley. 'Elepaio 37:40–41.

Simons, T., and C. Hodges (1998). Hawaiian Petrel (*Pterodroma sandwichensis*), version 2.0. In The Birds of North America (A. Poole and F. Gill, Editors). Academy of Natural Sciences, Philadelphia, PA, USA, and American Ornithologists' Union, Washington, DC, USA.

Sincock, J. L., and G. E. Swedberg (1969). Rediscovery of the nesting grounds of Newell's Manx Shearwater (Puffinus puffinus newelli), with initial observations. The Condor 71:69–71.

Spear, L. B., D. G. Ainley, N. Nur, and S. N. G. Howell (1995). Population size and factors affecting at-sea distributions of four endangered procellariids in the tropical Pacific. The Condor 97:613–638.

R Core Team (2013). R: a language and environment for statistical computing. Vienna, Austria. http://www.R-project.org.

Tennyson, A. J., and G. A. Taylor (1990). Behaviour of Pterodroma petrels in response to "war-whoops." Notornis 37:1–128.

Troy, J. R., N. D. Holmes, and M. C. Green (2011). Modeling artificial light viewed by fledgling seabirds. Ecosphere 2:1–13.

[USFWS] U.S. Fish and Wildlife Service (1983). Hawaiian Dark-rumped Petrel and Newell's Manx Shearwater recovery plan. Portland, OR, USA. http://kauaiseabirdhcp.com/mt-content/uploads/2016/05/recovery-plan_hawaiian-dark-rumped-petrel-and-newell_s-manx-shearwater_usfws-1983.pdf

Vorsino, A. E. (2016). Newell's Shearwater landscape strategy. Internal report. U.S. Fish and Wildlife Service, Ecological Services, Honolulu, HI, USA. https://www.fws.gov/pacificislands/documents/NESH%20Landscape%20Strategy_Final_Feb17.pdf

Vorsino, A. E., L. B. Fortini, F. A. Amidon, S. E. Miller, J. D. Jacobi, J. P. Price, S. O. Gon III, and G. A. Koob (2014). Modeling Hawaiian ecosystem degradation due to invasive plants under current and future climates. PLOS One 9:e95427.

Welch, A. J., A. E. Wiley, H. F. James, P. H. Ostrom, T. W. Stafford, and R. C. Fleischer (2012). Ancient DNA reveals genetic stability despite demographic decline: 3000 years of population history in the endemic Hawaiian Petrel. Molecular Biology and Evolution 29:3729–3740.