The Pueo Project

Annual Report 2018

Breeding phenology and daily activity of the Hawaiian Short-eared Owl (*Asio flammeus sandwichensis*) on O'ahu

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Introduction

The Hawaiian Short-eared Owl or Pueo (*Asio flammeus sandwichensis*), endemic to the Hawaiian Islands, is a subspecies of the Short-eared Owl (Strigidae; Berger 1981). As the only native raptor that breeds on all the main Hawaiian Islands, the Pueo plays an important role in top-down ecological regulation by controlling the population size of introduced rodents and preying on other native and introduced species, including birds and invertebrates (Mostello and Conant 2018). In addition, the Pueo is valued by native Hawaiians as an 'aumakua, or incarnation of an ancestor.

Despite their cultural and ecological importance, relatively little is known about the biology of the Pueo in the Hawaiian Islands. In our previous efforts (Cotin et al. 2018), we launched a study to estimate the population size and distribution of Pueo on O'ahu, where it is state-listed as endangered (DLNR 2005). We divided O'ahu into six vegetation types (grassland, wetland, agriculture, shrubland, alien forest, and native vegetation) and selected 35 sites at random to survey for Pueo. We selected 10 sites in grassland habitats which are the Short-eared Owl's preferred habitat in Europe and North America (Clark 1975, Mikkola 1983), and 5 each from the remainder. After conducting three standardized surveys at each site, we found that Pueo were more abundant in open vegetation types, with the highest concentration (3.3 Pueo per 100 ha) occurring in agricultural fields. No detections occurred in alien forest. We estimated the population of Pueo inhabiting O'ahu at 807 individuals, with 95% confidence intervals of 8 to 2199. During our surveys we witnessed multiple courtship displays (a prelude to pair formation and copulation; Clark 1975, Holt and Leasure 1993, Wiggins et al. 2006). In 2018, we broadened the scope of our research to include monitoring of breeding behaviors. We began an intensive search for Pueo nests shortly after completing our population size and distribution surveys in December 2017.

Globally, Short-eared Owl nests have proven difficult to find (Clark 1975, Martínez et al. 1998, Wiggins et al. 2006, Booms et al. 2014). Booms et al. (2010) surveyed for Short-eared Owls in Alaska via helicopter, and although they flushed on average one owl per 15 km of flight, they discovered only two nests after more than 400 km of on-the-ground transects. Clark (1975) discovered several nests on foot after observing courtship behavior, but females rarely flushed unless approached within 2.5 m of their nest. Keyes et al. (2016) dragged a heavy rope between two people to flush nesting females, but their study area was dominated by meadow and pasture, unlike ours, which is composed primarily of wetland vegetation, shrubland, and dense pineapple crop that prohibit this method.

While Short-eared Owl nests might be difficult to locate, their breeding behavior is more conspicuous: males perform aerial displays (wing-clapping; Fig. 1) to define territories and attract mates (Clark 1975, Holt and Leasure 1993, Wiggins et al. 2006), and they regularly provision their nests with prey (Holt and Leasure 1993), often just after sunset (Arroyo and Bretagnolle 1999). Although Short-eared Owls are generally crepuscular (Clark 1975, Wiggins et al. 2006), Pueo have been observed hunting during the day (Tomich 1971, Berger 1981, Mostello and Conant 2018), especially at higher altitudes (Fern Duvall, pers. comm.)

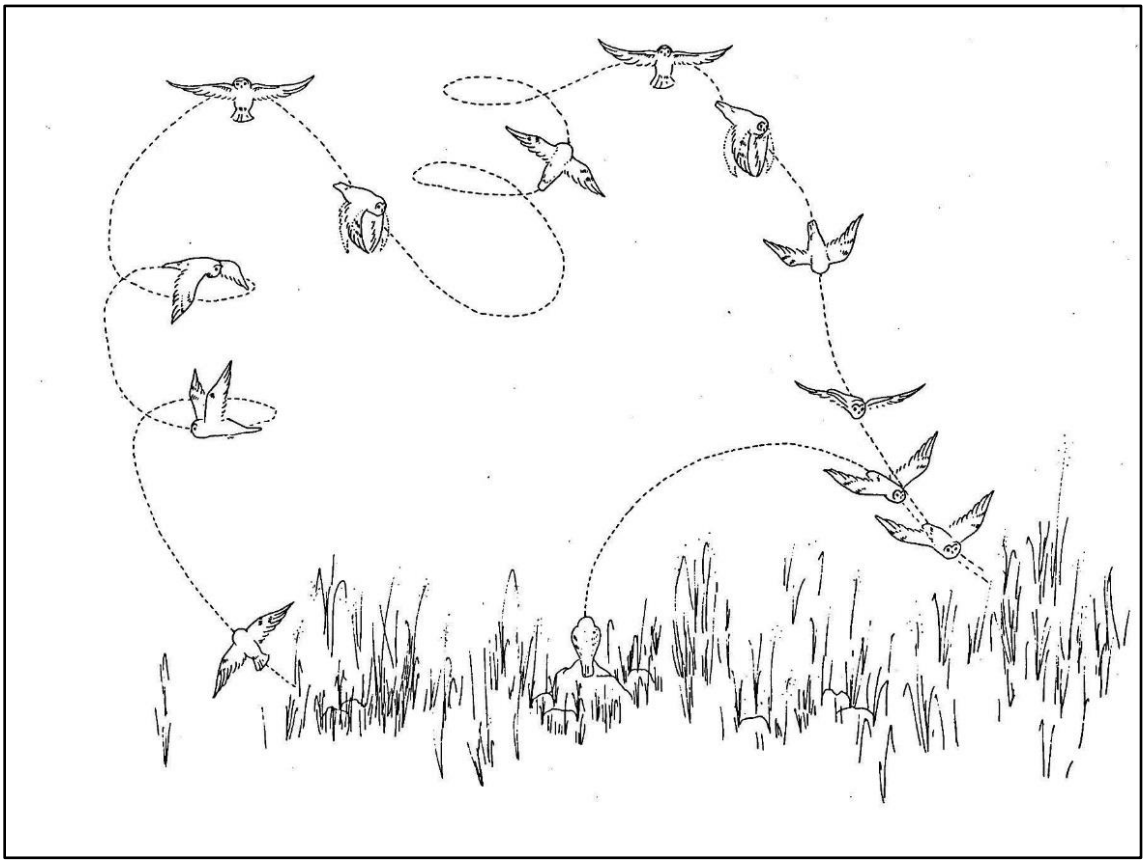

Figure 1. Illustration of a courtship display flight (Wiggins et al. 2006). The male soars above the landscape and rapidly trills his wings together. A female observes him from the ground, and later elopes to make a nest.

In this study, we conducted daily activity surveys to assess the optimum time of day to observe Pueo. We then conducted nesting activity surveys at the optimum time of day to observe courtship displays and prey provisioning.

Materials and Methods

Study area and site selection

We selected six sites (Fig. 2) in which pueo were sighted in 2017 to conduct focal studies of Pueo behavior in 2018: (1) Dole Plantation (Dole; 21°32'N, 158° 02'W), which consists of pineapple crop and fallow land interspersed with tracts of California grass (*Brachiaria mutica*) and alien forest; (2) Hamakua Marsh (Hamakua; 21°23'N, 157°44'W), a wetland bordered by shrubland and development; (3) Kawainui Marsh (Kawainui; 21°23'N, 157°46'W), an expansive wetland fringed by alien forest; (4) U.S. Navy Lualualei VLF Transmitter (Lualualei; 21°25'N, 158° 08'W), an expansive grassland encircled by alien forest and development; (5) Marine Corps Base Hawaii, Kaneohe Bay (MCBH-KB; 21°26'N, 157°45'W), a series of wetlands fringed by shrubland; and (6) University of Hawai'i West O'ahu (UHWO; 21°21'N, 158° 03'W), a mosaic of agricultural fields, shrubland, and scattered grasslands.

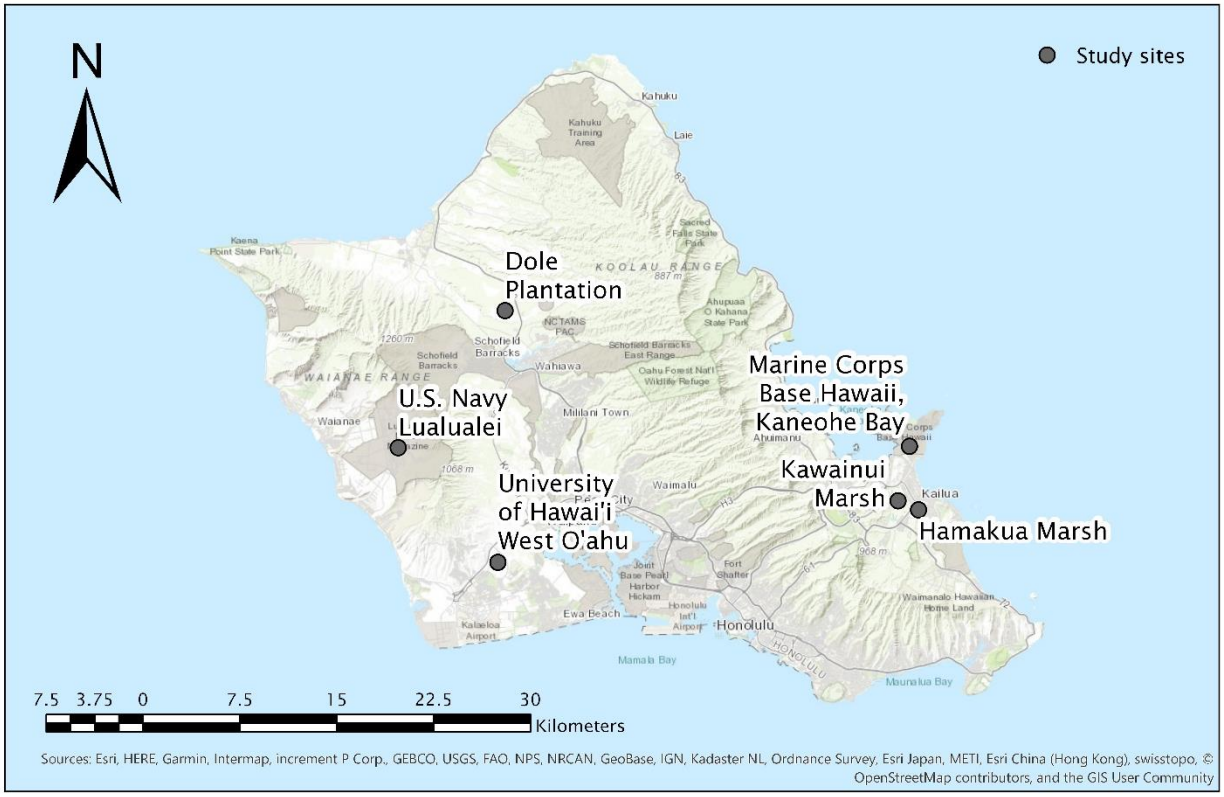

Figure 2. Our study area was limited to the island of O'ahu.

Daily activity surveys

We conducted a total of 20 focal surveys to determine Pueo daily patterns and behavior. Surveys were conducted at four sites (Dole Agricultural Lands, Hamakua Wetland, Lualualei, and Marine Corps Base Hawaii, Kaneohe Bay) between April 20, 2018 and June 17, 2018. Individual owls were observed and behavioral observations were recorded to the nearest minute. Pueo behaviors were categorized as soaring, hunting, wing-clapping, or perching. Observation times were standardized as minutes after civil twilight in the mornings and minutes until twilight in the evenings. Civil twilight was determined for the closest major city, Honolulu, according to data retrieved from timeanddate.com (2017). Surveys were designed to cover the whole day length but were divided evenly between morning and evening. Morning surveys started at civil twilight and ended 6.5 to 7 hours later, depending on day length. Evening surveys started 6.5 to 7 hours before civil twilight and ended at civil twilight. Barn Owl activity was incidentally recorded.

Breeding ecology surveys

To collect information on Pueo breeding activities, we conducted 101 surveys at six sites between December 30, 2017 and August 19, 2018. Following the methodology of our 2017 distribution surveys, breeding activity surveys started 60 minutes before sunset and ended at civil twilight. We recorded any courtship displays, prey provisioning, hunting behavior, and vocalizations, and tracked Pueo to their destination or point of origin. In addition, we included behavioral data from our 20 daily activity surveys, and from 30 of our 105 population surveys in 2017 (those which were conducted in our study area; Fig. 2). To standardize survey length, only observations recorded during the hour following sunrise or hour preceding sunset of daily activity surveys were used for this analysis. Barn Owl observations were incidentally recorded.

Analyses

Daily activity surveys. Relative Pueo activity was estimated as the number of Pueo observations per 30-minute interval. Time intervals were standardized to indicate time since civil twilight in the mornings or time until civil twilight in the evenings. We used a *t*-test to compare mean time between twilight and Pueo observations of morning and evening surveys.

Nesting activity surveys. We grouped surveys into two categories, those with Pueo detections and those without Pueo detections. Surveys with Pueo detections were further grouped by those where courtship displays were observed and those where courtship displays were not observed. We organized surveys by date and location to create a breeding phenology timeline across our study area.

Statistical analysis was carried out using SPSS 25.0.

Results

Daily activity surveys

A total of 21 Pueo detections were recorded during morning surveys and 32 Pueo detections during evening surveys. Most detections occurred within an hour of civil twilight (Figure 3). Mean time of detection in mornings and evenings was 91 minutes after civil twilight and 72 minutes before civil twilight, respectively (Figure 4). The distribution of detections did not significantly differ between morning and evening (DF = 51, T = 0.792, p = 0.432).

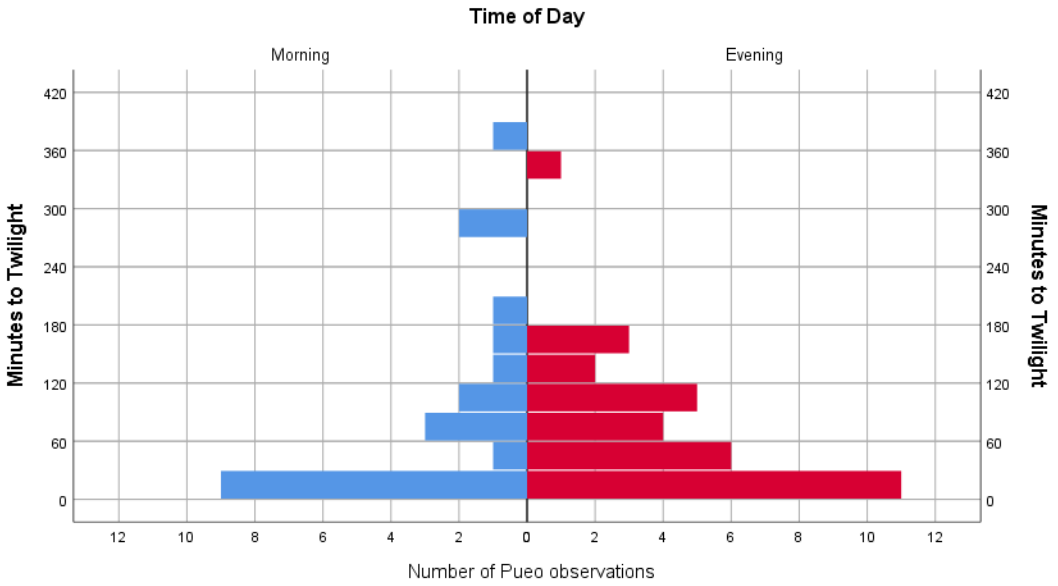

Figure 3. Pueo daily activity across four sites.

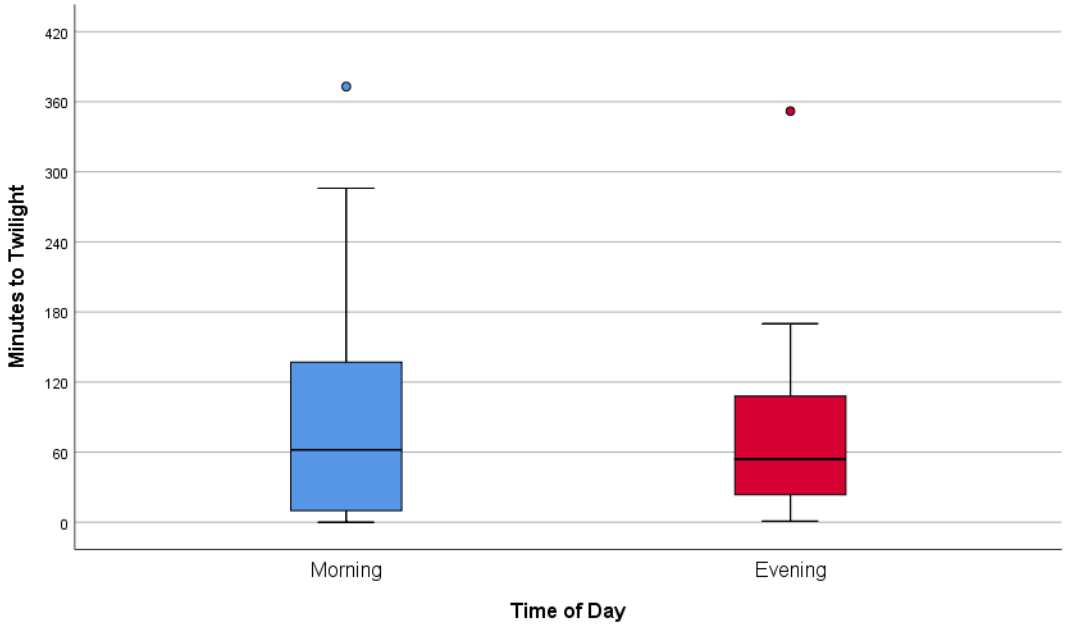

Figure 4. Pueo daily activity in relation to civil twilight.

The mean number of observations per survey in mornings and evenings were 2.1 and 3.2, respectively (Figure 5). There was no significant difference in number of observations (DF = 18, T = -1.530, p = 0.143).

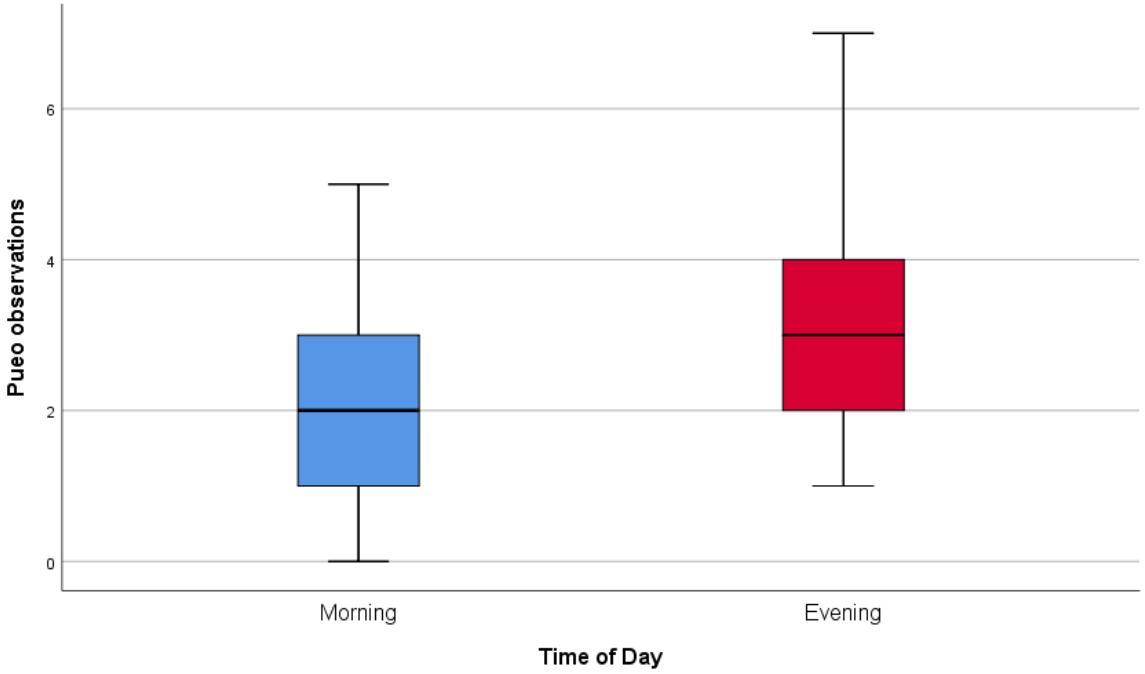

Figure 5. Pueo were more frequently detected in evenings than in mornings, but this difference was not statistically significant.

Nesting activity surveys

No prey provisioning of chicks was observed, and no nests were discovered. Including observations during the 2017 distribution surveys (Cotín et al. 2018), courtship displays were observed as early as November 2 and as late as June 10. Most displays occurred in February (n = 4), March (n = 2), and April (n = 3) across three sites (Fig. 6). Hamakua Marsh had the greatest number of Pueo observations (n = 29; Table 1), and Kawainui Marsh had the lowest (n = 0).

	Dole	Hamakua	Kawainui	Lualualei	MCBH-KB	UHWO
Total # of Surveys	46	29	8	24	29	15
Surveys w/ Pueo sightings	16	27	0	13	22	2
Surveys w/ Pueo courtship	6	4	0	0	3	0
% Sightings / Total	34.8	93.1	0.0	54.2	75.9	13.3
% Courtship / Sightings	37.5	14.8	0.0	0.0	13.6	0.0

Table 1. Total number of Pueo surveys, Pueo sightings, and courtship sightings per site.

Dole Plantation. Courtship displays were observed during six surveys, two in November, one in February, one in March, and two in April. Pueo were detected on about 35% of surveys (n = 46), but were frequently encountered on roads at night after our surveys had officially ended. Nighttime encounters were not included in this study because of the difficulty in observing Pueo without night vision equipment.
Hamakua Marsh. Courtship displays were observed on four surveys, one each in March, April, May, and June. Pueo were observed on about 93% of surveys (n = 29).
Kawainui Marsh. Eight surveys were conducted with no Pueo detections.
U.S. Navy Lualualei VLF Transmitter. Pueo were detected on about 54% of surveys (n = 24), however, no courtship displays were observed. Barn Owls were frequently observed hunting in daylight, occasionally at the same time as Pueo. One Barn Owl caught a prey item in an open field and flew into the forest [made a daytime prey provisioning to a chick or partner], but this was not investigated further.
Marine Corps Base Hawaii, Kaneohe Bay. Courtship displays were observed during three consecutive surveys in February. Pueo were observed on about 76% of surveys (n = 29). On May 30, 2018, a Pueo with a dark mask, typical of hatchling-year birds, was detected.
University of Hawai'i West O'ahu. Pueo were observed on about 13% of surveys (n = 15), however, no courtship displays were observed.

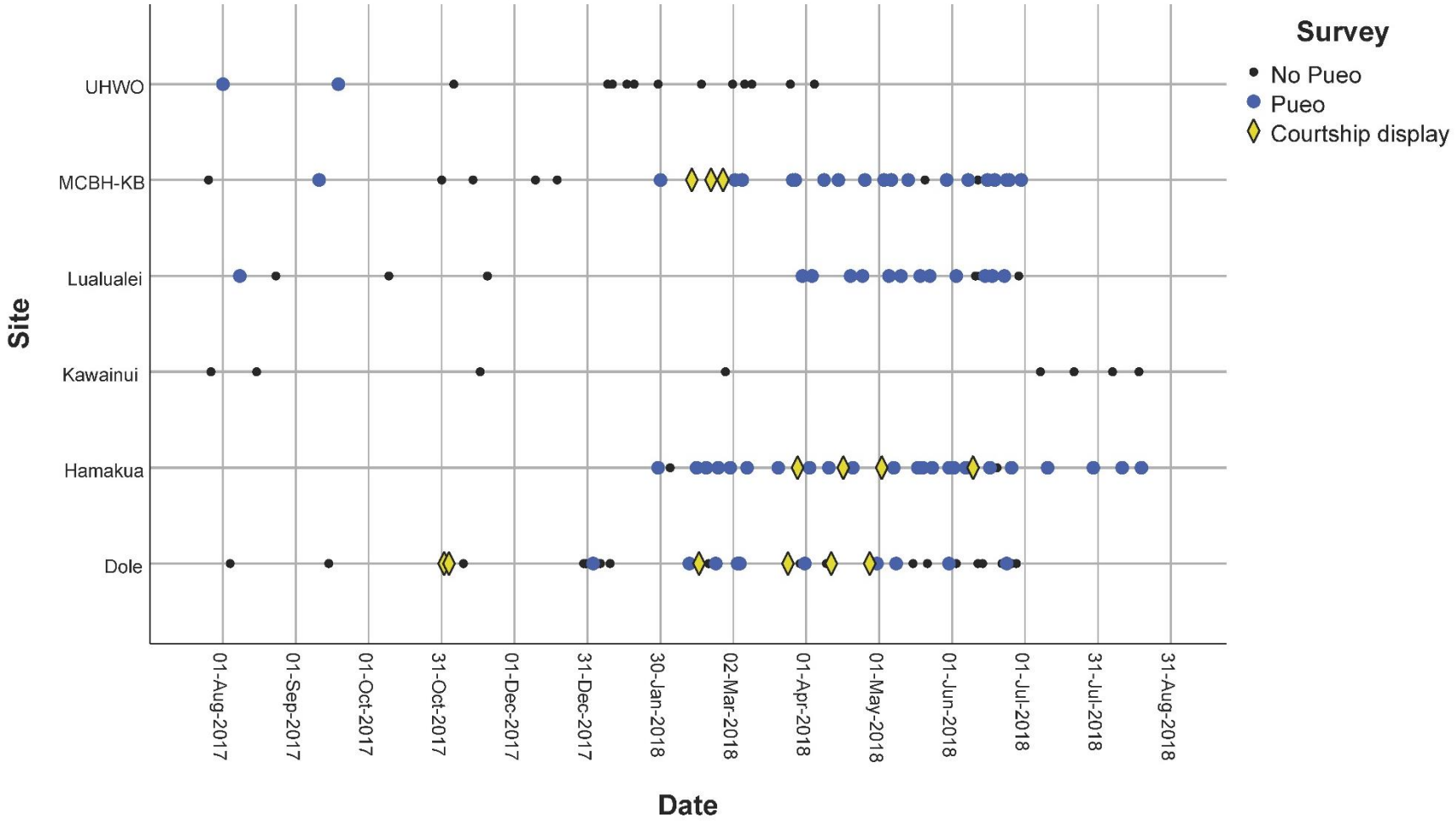

Figure 6. Breeding phenology by site (July 27, 2017 through August 19, 2018)

Discussion

Although the Short-eared Owl spans five continents and multiple island chains (Wiggins et al. 2006), most studies are limited to its breeding range, often at temperate or near-polar latitudes (see Table 2).

Study	Location	Latitude of study site
Miller et al. (2017)	Idaho, Nevada, Utah, and Wyoming (USA)	38°N to 46°N
Martínez et al. (1998)	Chile	40°S
Clark (1975)	New York (USA) and Manitoba (Canada)	43°N and 50°N
Johnson et al. (2013)	Wisconsin (USA)	44°N
Arroyo and Bretagnolle (1999)	France	46°N
Larson and Holt (2016)	Montana (USA)	47°N
Korpimäki (1994)	Finland	63°N
Booms et al. (2010)	Alaska (USA)	64°N

Table 2. Short-eared Owl studies, indicating their location and latitude.

Short-eared Owls at these comparatively high latitudes follow a predictable breeding season. In the northern hemisphere, pair formation begins as early as February (Wiggins et al. 2006) and runs as late as June (Clark 1975), with most broods occurring in April (Wiggins et al. 2006) and some in the high arctic as late as June (Pitelka et al. 1955). Short-eared Owls at these latitudes are commonly described as crepuscular (Clark 1975, Wiggins et al. 2006) and often provision their nests in low light conditions (Arroyo and Bretagnolle 1999). In addition, Short-eared Owl populations in the Holarctic are closely linked with prey abundance (Mikkola 1983, Korpimäki and Norrdahl 1991, Korpimäki 1994, Arroyo and Bretagnolle 1999, Poulin et al. 2001), which can fluctuate widely from year to year (Newton 2006, Wiggins et al. 2006).

While the Short-eared Owl is well described in Europe and North America, few studies document their breeding phenology or daily activity at tropical latitudes. Tseng et al. (2017) analyzed their movement and ecology in subtropical Taiwan at 24°N, but Short-eared Owls used their study area as a wintering ground, and no nests or courtship displays were observed. However, De Groot (1983) studied a subspecies of Short-eared Owl (*A. f. galapagoensis*) native to the Galapagos, a tropical island chain far removed from continental land masses, much like Hawai'i. De Groot (1983) confirmed that the Galapagos Short-eared Owl nests most months of the year and speculated that its breeding phenology was driven by the onset of the rainy season, which drives terrestrial prey cycles in the Galapagos (Grant and Grant 1980). De Groot (1983) also encountered the Galapagos Short-eared Owl at all hours of day, noting it could be diurnal, crepuscular, or nocturnal, depending on the island on which it was observed. Pueo may exhibit the same flexibility in daily behavioral cycles in the Hawaiian Islands. While our daily activity surveys suggest they are crepuscular in lowlands on O'ahu, reports from other islands in the archipelago (such as Kaua'i or Hawai'i) suggest that Pueo are more diurnal at cooler, higher elevations (Fern Duvall, pers. comm.)

Like the Galapagos Short-eared Owl, Pueo nests and owlets have been discovered at virtually all months of the year (Berger 1981). Because we observed courtship displays as early as November (Cotín et al. 2018), well outside the pair formation stage in North America (Clark 1975, Wiggins et al. 2006), we speculate that the Pueo has a more elastic breeding season than its continental counterparts. However, gathering further data regarding reproductive success remains a challenge. Although more than 100 nesting activity surveys were conducted over a span of seven months, no prey provisioning was observed.

While it is possible Pueo did not attempt to breed at any of our sites, the sheer frequency of their courtship displays, which reliably predict the beginning of the breeding season (Miller et al. 2017) and indicate breeding intent (Clark 1975, Holt and Leasure 1993, Wiggins et al. 2006), makes that prospect unlikely. We instead suggest that Pueo provision their nests exclusively at night, which would explain both the abundance of courtship displays and the scarcity of detected nests and daytime prey provisioning.

Unlike Short-eared Owls in North America and Europe, Pueo in Hawai'i do not contend with drastic changes in daylight throughout the breeding season. O'ahu is 21° from the equator; daylight fluctuates by less than three hours throughout the year (Anon 2017). In contrast, high latitude sites experience shorter periods of darkness in spring and summer. Sites at 50°N or greater experience no darkness at all as the June solstice approaches (Anon 2017). Because Short-eared Owls in the Holarctic often breed at these near-polar latitudes in late spring and early summer (Pitelka et al. 1955, Clark 1975, Wiggins et al. 2006), it follows that they must inevitably hunt in daylight or twilight if they are to provision a nest. However, Short-eared Owls at lower latitudes demonstrate more variable foraging behavior (Tomich 1971, De Groot 1983). Our daily activity surveys, which show a bimodal distribution, indicate that Pueo on O'ahu are crepuscular. Nighttime roadway encounters while researchers were leaving the survey areas also indicate that Pueo are active during nocturnal hours. Because night-time darkness lasts 7.5 hours or longer throughout the year in the main Hawaiian Islands (Anon 2017), it is conceivable that Pueo are crepuscular-nocturnal foragers year-round.

Although no nests were found, and no prey provisioning of chicks observed, we have reason to believe that Pueo successfully reared young at the Marine Corps Base Hawaii, Kaneohe Bay (MCBH-KB). On May 30, 2018, a Pueo was observed with a dark mask, typical of recently fledged juveniles (Witherby et al. 1941). Two pieces of circumstantial evidence lend further support: (1) on May 18, 2017, prior to our island-wide population surveys, we discovered a downy Pueo owlet that had wandered from its nest at MCBH-KB, indicating successful reproduction the previous spring; and (2) courtship displays were observed during three consecutive surveys in February 2018, followed by 19 surveys with no courtship displays, which suggests a strong possibility of successful pair formation and nesting. Assuming an incubation period of 29 days (Tate 1992), a nest dispersal of 14 days (Holt et al. 1992), and a first flight of 27 days (Clark 1975), we estimate an egg at MCBH-KB could have been laid as late as March 21, 2018, although it could have been laid much earlier.

A literature search suggests that many Pueo nests in Hawai'i are discovered purely by chance. Snetsinger (1995) recorded three nests on the slopes of Mauna Kea while conducting presumably unrelated native bird surveys. Our colleagues have also serendipitously discovered Pueo nests during unrelated field work; one nest was found on Maui during a vegetation transect in November 2011 (Forest Starr, pers. comm.), while another was discovered in May 2017 while searching for seabird burrows in the mountains of Kaua'i (André Raine, pers. comm.) Furthermore, Pueo nests have been discovered at drastically different altitudes. On Maui, nests have been discovered in wetlands near sea level and in native vegetation at 2,000 m in elevation (Fern Duvall, pers. comm.) Because Pueo likely provision their nests at night, to increase effectiveness in future studies, surveys will almost certainly require night vision equipment, more survey hours, and a healthy spate of luck if they are to uncover nests on O'ahu with any regularity.

Appendix

Owl pellets

We extensively searched Hamakua and Lualualei for owl pellets following observations of roosting Pueo (Katie Doyle and John Green, pers. comm.) Pellets were individually placed in plastic bags and delivered to the Bishop Museum in Honolulu, Hawai'i for long-term storage. Although no analyses were conducted at the time of publication, these samples will be dissected in 2019.

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