THE URBANIZATION OF THE HAWAIIAN STILT (*Himantopus Mexicanus Knudseni*): MEETING THE NEW NEIGHBORS

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ABSTRACT

The Hawaiian stilt, or *Ae‘o*, is an endangered waterbird endemic to the Hawaiian Islands. Loss of suitable wetland habitats due to anthropogenic development is a leading cause for decline, as well as the introduction of non-native predators and invasive wetland plants. While other Hawaiian waterbirds are largely restricted to wetlands, Hawaiian stilts appear to be adapting to the urban environment, using heavily modified upland habitats. In my thesis study, I fitted four Hawaiian stilts with GPS satellite tags to document their use of developed areas, undeveloped fields, sports fields and wetland habitats over a 6-month period. I found a high use of non-wetland habitat, with significant differences in habitat occupancy among the individual stilts and across different times of day. Wetlands were the dominant habitat occupied from morning to early afternoon, but non-wetland habitats were occupied in higher frequency in the evening and early morning hours. The use of habitats outside wetlands implies management strategies may need to be updated to encompass these additional habitats.

INTRODUCTION

Wetlands typically occupy just a small fraction of the landscape, but are disproportionately important for a number of ecosystem services and wildlife habitat. Wetlands are transition zones where land and water are linked, where the water table is fairly close to the surface. These places provide valuable functions such as recycling nutrients, purifying water, maintaining stream flow, mitigating floods, recharging groundwater, and buffering shorelines against erosion (Finlayson et al. 1999). Wetlands also serve as critical habitat for many species of wildlife, including important refueling and resting habitat for migratory birds, nurseries for marine fisheries and feeding and nesting habitat for many resident species. Unfortunately, wetlands are some of the most threatened
habitats globally (Prasad et al. 2002), with ongoing anthropogenic pressure from filling and dredging, large scale changes in land use, and alterations to the upland watersheds. An estimated 87% of the world’s wetlands have been lost (Davidson 2014), and the conservation of waterbirds is tied directly to quantity and quality of wetlands.

Historically, the Hawaiian Islands supported a diversity of waterbird species, with at least 30 species known from human accounts and fossil records (Olson and James 1982; USFWS 2011). Today, only six remain, all of which are listed as endangered species (USFWS 2011). Four of these waterbirds are reliant on wetlands on the main Hawaiian Islands, with loss of wetland habitat is one of the main contributors to their endangerment (Reed et al. 1998). Of these waterbirds, the Hawaiian stilt, or Ae’o (Himantopus mexicanus knudseni), has the largest distribution across the state of Hawai‘i, and is still found on all the major Hawaiian islands year round (Banko 1988; Reed and Oring 1993; Underwood et al. 2013). The Hawaiian stilt is a subspecies of the North American black-necked stilt. It has federal and state protection and categorized as an endangered species by the IUCN red list. Hawaiian stilt populations hover around 1600 for the whole state according to biannual waterbird counts (Hawaii biannual waterbird data). Hawaiian stilts historically only occurred on the larger of the main islands but with development they are now found on all island year round or seasonally with the exception of Kahoʻolawe (Hawaii biannual waterbird data).

The proper Hawaiian name given to the Hawaiian stilt is Kūʻuluæʻo. This name is also shared by the Ohe maikai (Reynoldsia sandwicensis), a threatened dryforest tree in the Araliaceae family (Native Plants Hawaii 2009). In Hawaiian culture, many flora and fauna have a sister species to indicate the connectivity between the realms of life from ocean to the summits of the mountains or wao. During the makahiki, Hawaiian solstice, Ohe maikai were used to make stilts
for a festival game of keep away kick ball (Native Plants Hawaii 2009). Hawaiian stilts are the *kinolau*, physical manifestation of the Hawaiian god *Kū* in his fisherman form. In this form for *Kū*, Hawaiian stilts were culturally significant as indicator species. A *moʻolelo*, proverbial saying, about Hawaiian stilts said that they tell the fishermen when to go out to fish in the morning (Pukui 1983). The Hawaiian translation of *kūkuluaʻo* is to stand tall, as to be a pillar. Hawaiian stilts were also viewed as protectors and keystone species within wetlands. Hawaiian stilts are the more frugal of the waterbirds within wetlands so when it was seen that their numbers declined the wetland was indeed in a dire state.

The island of Oʻahu has the largest population of Hawaiian stilts despite having lost 65% of wetlands since pre-development (USFWS 2011; van Rees and Reed 2014), especially low-elevation wetlands which are preferred by Hawaiian stilts (Henshaw 1902; van Rees and Reed 2014). Hawaiian stilts are typically found in open wetlands that are sparsely vegetated and have areas with shallow (< 130 mm) water (Coleman 1981). Both perennial and ephemeral wetlands that experience seasonal inundation and evaporation are important for Hawaiian stilts during breeding and for feeding and resting (Robinson et al. 1999). However, very little is known about how variability in habitat quality and landscape-level factors such as the geographic distribution of wetlands affect their use of different habitats and movement among different wetlands. Considering these birds’ conservation status, better information on habitat use is needed for effective habitat management and conservation.

Although Hawaiian stilts are managed as waterbirds (USFWS 2011), with the emphasis on protection of wetlands, incidental observation of stilts in upland habitats suggest habitat flexibility of the species. For example, studies of Hawaiian stilts have documented occurrences in upland habitats such as sports fields, and agriculture and aquaculture fields (Engilis and Pratt 1993; eBird;
Hawai‘i Division of Forestry and Wildlife, unpublished data). These new habitats are generally far from areas of management and protection, however, the frequency of occurrence in these upland habitats is poorly known. These upland as well as wetland habitats are scattered across the landscape, with areas of presumably unsuitable habitat such as mountains, interstate highways, military bases, and urban centers separating them. The degree to which stilts are moving through this complex landscape has important implications on connectivity among core sites and rates of mortality. While Hawaiian stilt recovery is focused on core and supportive wetlands where hydrology manipulation is practiced or natural areas are protected from additional anthropogenic development (USFWS 2011), the incidental observations of upland use and the movement among sites indicate there may be additional challenges for the species, and managers may need to expand habitat parameters for conservation.

To quantify habitat use in and outside of wetlands and evaluate the spatial behavior of stilts, we utilized GPS satellite tracking tags to document daily movement over a 6 month period. Our objective was to identify important habitats and assess whether there was daily and season patterns of the movement. This work is important to understand the full range of habits required by this endangered species.

METHODS

We had two wetland complex study areas, Pearl Harbor on the western side of O‘ahu Island, Hawaii, and the Kaneohe area on the eastern side of the island. Within the Pearl Harbor wetland complex we captured birds at Fort Kamehameha Reef Flats (Āhua Reef) (21°19'01.6"N 157°57'28.3"W), a mitigation wetland adjacent to the Honolulu international Airport, and the Pouhala Marsh Wildlife Sanctuary (21°22'38.5"N 158°00'22.0"W), an ephemeral state managed
natural wetland. On the eastern side of O‘ahu our study site was on the Marine Corp Base Hawaii (MCBH) at the Reclamation Treatment Facility (21°26'17.3"N 157°45'30.2"W), a wastewater treatment facility adjacent to a series of freshwater wetlands. Abundant invertebrate food sources are considered to be one of the factors that attract waterbirds to the wastewater treatment ponds.

I caught Hawaiian stilts using 16 x 32 ft dropnets (Doherty 2009) and wooden decoy lures. Captured stilts were marked with unique color leg band combinations consisting of a Federal Bird Band and three plastic color bands to form a unique color combination. Hawaiian stilts were outfitted with Lotek Pinpoint GPS solar satellite tracking tags, attached using a leg-loop harness design (Rappole and Tipton 1991) with ¼ inch Teflon ribbon and a rubberband weak-link design (Kesler 2011). GPS Satellite tags were programmed to log a location once every 1.5 hours from 4 AM to 8 PM daily Hawaii Standard Time (before sunrise to after sunset). The solar powered tags would go offline periodically, presumably due to low power levels resulting from periodic covering of the solar panel from feathers, and sometimes there was a week of missing data until tags came back on line. Data was downloaded from the Argos Satellite web platform, and Lotek’s Argos-GPS Data Processor V3.18 was used to decode the downloaded files. We used Program R to convert Greenwich Mean Time to Hawaii Standard Time, convert longitude and latitude to UTM zone 4 and formatted the files for input into ArcGIS (ESRI, Inc).

In ArcGIS, we used high resolution aerial satellite photography from WorldView-2 (2016) to quantify habitat into four categories for each location: Developed areas, defined as areas with industrial or housing development present; Undeveloped fields, defined as cleared land that has not been developed; Sports fields, defined as areas with mowed grass, scattered trees, and frequent recreation activities; and Wetland habitats, defined as wetlands and other areas
influenced by frequent or permanent water presence. Additionally, we classified locations by whether they were in areas under active management for the benefit of waterbirds, regardless of level of active management (e.g., water level manipulation, predator control, weed control).

We assessed daily habitat use patterns by grouping locations into the hour they were recorded (12 categories). To evaluate whether night roosting locations were influenced by the lunar phases, we pooled observations from each five day period around the full moon and new moon phase using the location from the pre-dawn (4am) period, determined to be the darkest period during the logged time series and most likely to reflect roost location. To test for differences in habitats used among individuals, times of day, and across lunar cycles, we used a Pearson’s Chi square analyses conducted in Program R. All location data was archived in MoveBank.org under project name “Hawaiian Stilt GPS movement”.

RESULTS

We captured four Hawaiian stilts between 19 July – 02 August 2017. Within Pearl Harbor, one bird was transmittered at Pouhala Marsh and its tag was active between 19 July – 12 October 2017. Two birds were transmittered at Āhua Reef with tags active between 20 July 2017- 12 February 2018. The fourth bird was transmittered in Kaneohe on 2 August 2017 and its tag was also active until 12 February 2018. GPS locations logged by individuals ranged from 276 to 854 (Table 1). Movement patterns varied among individuals, with average movement among individuals ranging from 88 m to nearly 2 km, and maximum distances of up to 10.6 km (Table 1).

We found that the stilts utilized multiple locations over a relatively large area (Table 1, Figs. 1, S1). Our habitat classification of locations indicate that Hawaiian stilts used both urban
and semi-natural habitat types, with an average 66% of locations in wetland habitats, 18% in developed areas, 12% in undeveloped fields and 5% of locations in sports fields (Fig. 1). Habitat use among individual birds tracked was significantly different ($\chi^2_9 = 166.21$, $P < 0.001$), with three distinct habitat use patterns noted. The bird captured at Pouhala (Tag 38) spent over 90% of its time in the wetland, which is likely attributable to the bird being a parent with a dependent chick in the wetland during the period of tracking. In contrast, the Kaneohe bird (Tag 39), spent 53% of its time adjacent to a wastewater reclamation plant, which provided abundant food resources in the treatment tanks. The last two birds captured at Āhua Reef (Tags 37 and 41) were caught together, and they showed very similar habitat use patterns over the course of the 6 months. Because the Pouhala bird’s tag died early and most of the tracking period was during a time with dependent young, we excluded the bird from further habitat use analysis (below).

Only 46% of the total 2420 GPS locations recorded were in habitat that had some form of active management (e.g., fencing, predator trapping, invasive plant control), with wetland habitats having the highest levels of protection (71% of wetland locations), followed by developed areas (11% of locations), undeveloped fields (9% locations), and sport fields (0% protection) (Table 1). The percent of occurrence in managed habitat varied from 0% to 97% among individuals, reflecting the high variability among individuals in terms of habitats occupied.

The habitat Hawaiian stilts occurred in varied significantly from 0400 to 2000 hours as a function of time of day ($\chi^2_{33} = 241.22$, $P < 0.001$) (Fig. 2). Wetland habitats had the highest use during the day after the early morning hours, with the percentage of locations in wetland habitats above 60% from 0700 to 1400. However, in the late afternoon into evening (as well as early mornings) wetland habitat occupancy decreased to 38% of total habitat use on average (Fig. 2).
Occurrence in non-wetland habitats such as undeveloped fields and developed areas was highest in the mornings and evenings (Fig. 2).

We found that night-time habitat use (based on pre-dawn locations) was significantly different between periods of the full and new moon cycles ($\chi^2 = 38.19, p < 0.001$). During the new moon cycle, sports fields, developed areas and wetland habitats were used at similar levels (Fig. 3). However, during the full moon lunar phase, occupancy in urban developed areas and undeveloped fields increased by 34% and 70% respectively, while wetland habitats and sports field occupancy decreased by 90% and 29% respectively compared to the new moon habitat use proportions. There was no difference in the habitat locations during the pre-dawn (04:00) and post-sunset (20:00) locations during the new moon ($\chi^2 = 0.62, p = 0.89$), but there was a significant difference in habitat use between evening and pre-dawn locations during the full moon ($\chi^2 =25.26, p<0.001$). Specifically, wetland habitat use decreased from 18% to 3% between 20:00 and 04:00 during full moon cycles and sports field use increased from 3% to 20%.

**DISCUSSION**

This study documented extensive use of upland habitat by Hawaiian stilts. While Hawaiian stilts are generally classified and managed as wetland birds, our observations of stilt movement showed a pattern of habitat use previously undocumented by other Hawaiian stilt studies, particularly the use of upland and urbanized habitats. Only through the use of satellite tracking devices could we have followed these highly mobile species, and fully appreciate the breadth of habitat use. Many species of birds have been documented using human-dominated landscapes, indicating these habitats can have some value for some species (Blair 1996;
The North American black-necked stilt will spend time in modified wetlands, wetlands with seasonal hydrology manipulations, and flooded agriculture fields as foraging habitats (Elphick 2000), with the selection of “wet soil” habitats in North American black-necked stilts strongly correlated with water depth (Isola et al. 2000). However, the well-draining habitats such as airfield runways and parking lots that we observed Hawaiian stilts using varies from these modified habitats. While Hawaiian stilts prefer exposed mudflats with low growing interspersed vegetation (USFWS 2011), undeveloped fields and sports fields can resemble these habitats, especially after exposure to flooding from rain events, and may make them attractive to Hawaiian stilts for foraging and nesting. Other studies have also reported that disturbed or actively-managed fields may provide increased foraging opportunities and serve as alternative semi-natural wetlands for migratory wading bird and other wetland species (Elphick 2000; Li et al. 2013; Price et al. 2013). Additionally, it is possible that Hawaiian stilts are using these alternative sites to gather resources absent from natural wetlands or are attracted to these sites for other reasons, such as safer roosting locations. Overall, 35% of all habitat locations were in developed areas and undeveloped fields, which may have some similarities to the stilt’s wetland habitats given exposure to flooding from rain events. However, these areas differ from their wetland habitats in that there is greater potential for interactions with humans, higher rates of evaporation, no conservation management, and possibly higher exposure to mammalian predators.

Despite stilt’s substantial use of human modified upland sites, wetland habitats were still very important to the tracked Hawaiian stilts, with over half the locations recorded occurring in wetlands. However, the uses of alternative habitats throughout the day suggests birds maybe maximizing the benefits of different habitat for foraging, resting, and breeding. For example,
some habitat may provide lower predation risks for roosting, but other habitats provide better foraging habitat. Wetland habitat use was highest during the day, and this may coincide with peak foraging times. On the other hand, upland habitats were used in higher proportions in the early mornings and late evening hours, and this may be a period when loafing and roosting are more important. In the Yellow Sea, migrating shorebirds will utilize salt-pan and dried shrimp farm ponds as habitat when tidal flats are unavailable (Sripomolyom et al. 2011; Li et al. 2013), and many nocturnal species utilize contrasting habitats to meet their needs for diurnal shelter and alternative nocturnal foraging habitats (Law and Dickman 1998). The ability for stilts to use a range of habitats may be one of the reasons they have the greatest distribution of the Hawaiian waterbirds (USFWS 2011).

Hawaiian stilts also varied nocturnal habitat use by moon phases, estimated from predawn habitat locations. During a new moon, there is a broad use of wetland and upland habitats, but during the full moon the use of wetland habitat drops to very low levels. Many of the upland habitats stilts were detected in habitats with abundant urban lighting, which may have allowed the stilts to forage at night. However, we do not know whether habitat use is primarily for roosting, or is also selected for nocturnal foraging. Wading birds will opportunistically forage in urban lighting close to estuaries to take advantage of crustaceans that become more visible because of anthropogenic light sources (Rompré and McNeil, 1996). Anthropogenic light has also been documented to alter foraging behaviors in other wading and shorebirds in the evening (Burger and Gochfeld 1991; Santos et al. 2010). Sanderlings during winter migration will forage in larger flocks and increase time probing for food sources in artificial light (Santos et al. 2010). Anthropogenic light may also attract arthropods, and Hawaiian stilts, which are generalist feeders, possibly use these habitats for nocturnal foraging. During full moon cycles, in contrast
to new moon periods, there was a significant difference between post-sunset and pre-dawn habitat, indicating stilts are moving among habitats at night, perhaps to forage. Increases in upland habitat use at night may indicate a strategy by Hawaiian stilts to maximize foraging opportunities in an urban environment. Hawaiian stilts may also use these lighted habitats to increase their ability to see mammalian predators. However, the decrease in use of wetland habitats during the full moon is counterintuitive to a predator detection hypothesis, and more work is needed to understand the value of nocturnal habitats.

Wetlands within Hawai‘i are the focus of considerable conservation resources targeted for the protection and persistence of endangered waterbird species like the Hawaiian stilt. When Hawaiian stilts use habitats outside of key wetland management areas they may be exposed to different threats. While the Hawaiian Waterbird Recovery Plan (USFWS 2011) notes the use of non-wetland habitats, the plan does not discuss the potential importance of these non-wetland habitats to the recovery of Hawaiian stilts. The results from this study highlight that these non-wetland habitats may be very important to Hawaiian stilts for their recovery. The Hawaiian waterbird recovery plan recommends that all core wetlands and 50% of supportive wetland habitats have predator management on site, but outside of managed wetland habitats Hawaiian stilts may have increased exposure to mammalian predators and disease vectors, higher risks of strikes (both aircraft and buildings), as well as general increases in interactions with humans. Management actions that target these ‘non-typical’ habitats may help in the recovery of the stilts by minimizing mortality and maximizing carrying-capacity. However, even within managed wetlands the level of management is variable, creating a spectrum of management practiced by different land managers. More research is needed to understand the benefits of these upland habitats, as well as measure whether they are increasing stilt’s exposure to predators.
Anthropogenic borders are meaningless to the stilts, and given the high mobility of the tracked stilts across management jurisdictions, management should be a collaborative effort. As climate change impacts available coastal habitats, and sea level rise is projected to reduce coastal habitats, stilts may increasingly depend on inland habitats where they may be exposed to increase risk (Chang 1990; Underwood et al. 2013). While multiple models offer predictions as to how coastlines will change, regional and geological differences are capable of exacerbating the effects of sea level rise (Galbraith et al. 2002, Traill et al. 2011). Conservation planning for Hawaiian stilts should incorporate these uncertainties when planning for the long-term persistence of the species. The results from this movement study will provide useful information for management plans for Hawaiian stilts to better protect these birds across the range of habitats they utilize.

FUTURE RESEARCH SUGGESTIONS

Additional research could focus on increasing the sample size of Hawaiian stilts, increasing the time logged on the tags and including tidal, lunar and seasonal rain and management efforts into the analysis. Other additional data can be gathered on these nocturnal habitats and the value they offer to Hawaiian stilts. Through increasing the sample size of stilts it would be possible to understand more of the overall O’ahu population than just the very small sample of four individuals, perhaps a sample size of 60, with 20 birds from the three core regions of habitat, on O’ahu would enable the waterbird management community to have a better general understanding of these dynamic habitat uses. Increasing the log time to 24 hours and the log frequency to .5hrs would allow waterbird managers to have a finer understanding of the movements and time outside of wetland habitat use. This also could be obtained by focusing log times to the hours when Hawaiian stilts are outside of wetlands from the hours of 5pm (1700 hrs) to 5am (0500hrs).
Hawaiian stilts are supported by agency management within protected wetlands, for the recovery of Hawaiian stilt it is valuable for managers to understand the non-wetland use of Hawaiian stilts and the areas within the urban O’ahu setting where management can be directed, or urban habitat use can be encouraged. There are factors I did not look at within my study that future studies could build on. I did not look at how the natural tidal influx, full lunar cycles or seasonal rainfall alter the use of the four habitats by Hawaiian stilts. Other waterbirds within urban settings will opportunistically feed by following grass mower to feed on the insects that are disturbed when grasses are cut. Inertly shore and waterbirds are attracted to habitats where tidal influx occurs for feeding and for safety from predators. Another study that can use this small sample of habitat variability would be to set motion cameras, time lapse cameras within the highly visited urban habitats to capture the habitat use of Hawaiian stilts. During the evening when habitat use in wetlands is low it would be valuable for the management and recovery of Hawaiian stilts to understand the attractiveness of non- wetland habitats. Areas with increase light may increase food resources by attracting potential food sources or increase safety in the light sources increasing the Hawaiian stilts ability to identify threats. The variable habitat use of Hawaiian stilts makes them flexible to the urban habitat; management for the recovery of the Hawaiian stilt could include these non-traditional habitats in the future once more is understood about this habitat use.

ACKNOWLEDGEMENTS

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LITERATURE CITED


Henshaw, H. W. 1902. Birds of the Hawaiian Islands: being a complete list of the birds of the Hawaiian possessions, with notes on their habits. TG Thrum.


Table 1. Monitoring period, number of locations, mean, median, and maximum distance between locations, and habitat occurrence in the four Hawaiian stilts tracked on Oahu Island, Hawai‘i. For locations detected in, the percentage that are managed for waterbirds, regardless of management activity, is indicated.

<table>
<thead>
<tr>
<th>Tag</th>
<th>Monitoring period</th>
<th>Number of Locations</th>
<th>Mean, median, maximum distance (m)</th>
<th>Wetland (% managed)</th>
<th>Sports field (% managed)</th>
<th>Undeveloped Field (% managed)</th>
<th>Developed Area (% managed)</th>
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<tr>
<td>37</td>
<td>Jul 20, 2017 - Jan 30, 2018</td>
<td>778</td>
<td>Mean: 1,905</td>
<td>510 (93%)</td>
<td>66 (0%)</td>
<td>124 (5%)</td>
<td>78 (53)</td>
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<td>Median: 901</td>
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<td>Mean: 88</td>
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<tr>
<td>38</td>
<td>Jul 19, 2017 - Oct 12, 2017</td>
<td>276</td>
<td>Mean: 88</td>
<td>269 (100%)</td>
<td>6 (0%)</td>
<td>0 (0%)</td>
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<td>Mean: 366</td>
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<td>39</td>
<td>Aug 02, 2017 - Feb 12, 2018</td>
<td>854</td>
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<td>Mean: 1,533</td>
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<tr>
<td>41</td>
<td>Jul 20, 2017 - Feb 10, 2018</td>
<td>512</td>
<td>Mean: 1,458</td>
<td>292 (91%)</td>
<td>48 (0%)</td>
<td>129 (16%)</td>
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<td>Max: 10,615</td>
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Figure 1. Relative frequency of habitat associated with locations detected from individual Hawaiian stilt tracked on Oahu Island, Hawai‘i.

Figure 2. Average frequency of Hawaiian stilts habitat occurrence by time of day, July 2017 – February 2018, Oahu Island, Hawai‘i.
Figure 3. Frequency of habitat types for Hawaiian stilt pre-dawn (4 AM) locations during full and new moon lunar phases. For each lunar phase, the 5 days centered around each phase were averaged.
Supplemental material

Figure S1. Locations of individual Hawaiian stilts on Oahu Island, Hawai‘i. Each dot is a specific location overlaid a WorldView-2 (2016) satellite map.