NEST SITE SELECTION AND PREDATOR IMPACTS ON THE REPRODUCTIVE SUCCESS OF THREE ENDANGERED WATERBIRDS IN HAWAIʻI.

A THESIS SUBMITED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAIʻI AT MĀNOA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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GLOBAL ABSTRACT

Precocial species leave the nest soon after hatching, making them vulnerable to a variety of threats as they search for food and shelter prior to gaining the ability to fly. Adaptive habitat-selection theory suggests that animals should select areas with habitat characteristics that maximize fitness, so species with precocial chicks should select nesting areas with characteristics that maximize success during both the egg and chick stages. Recent studies suggest that endangered species recovery may be hampered when predator impacts differ between nest and chick stages, requiring different management strategies to protect across the reproductive stages. Predation of the egg and chick stages are a major cause of reproductive failure in three endangered Hawaiian waterbirds, the Aeʻo (Hawaiian Stilt; *Himantopus mexicanus knudseni*), the ʻAlae keʻokeʻo (Hawaiian Coot), and ʻAlae ʻula (Hawaiian Gallinule; *Gallinula galeata sandvicensis*), but predator types likely differ between stages, making them an ideal species in which to examine relationships between nest-site selection, predator types, nesting and fledging success. In this study, we utilized motion-activated game cameras at nests and tracking of chicks to evaluate: (1) which nest-site characteristics are related to egg predation by different species; and (2) the relationship between habitat characteristics, predator detections at the nest, and fledging success. (3) which nest-site characteristics and predator detections at nest are related to chick survival by different species; and (4) what is the relationship between predator detections and nest site characteristics with chick fate by the two Hawaiian waterbird species. Using a linear and binomial logistic regression and exposure models, we found that nest concealment of vegetation (vegetation density) was not a predictor for predation risk at both the nest and chick stages. We found a 5% increase in stilt chick survival over the nesting season and a 5% decrease in gallinule chick survival over the nesting season, suggesting seasonal changes in food abundance or predation risk. ʻAlae ʻula chicks were detected in American Bullfrog stomachs, confirming them as a source of chick, but not egg, mortality. Based on our results, management actions aimed at improving nesting success will not simultaneously improve chick survival, with the exception of the removal of mammals, which benefits both. A critical need to improve outcomes for chicks is the development of better control options for invasive reptiles, amphibians, and invertebrates.

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Chapter 1: Impacts of Predators on Nesting Success of Hawaiian Stilts (*Himantopus mexicanus knudseni*), Hawaiian Gallinules (*Gallinula galeata sandvicensis*) & Hawaiian Coots; *Fulica alai*).

ABSTRACT

Ground-nesting birds are susceptible to predation of eggs during the nesting stage, as nests are accessible to a diverse group of predators, both native and invasive (Schüttler et al., 2009). Predation is a major cause of nest failure in the Hawaiian Stilt (Ae‘o; *Himantopus mexicanus knudseni*), Hawaiian Coot (‘Alae ke‘oke‘o; *Fulica alai*), and Hawaiian Gallinule (‘Alae ‘ula ; *Gallinula galeata sandvicensis*) populations (USFWS, 2011). However, a research gap exists on the differential impacts of different predator species on these three Hawaiian waterbird species and the relationship with nest site characteristics. To address this apparent research gap regarding differential impacts of potential predator species on ground-nesting waterbirds based on their nest-site characteristics, we utilized a combination of visual nest checks and motion-activated cameras to determine the relationships among predator detections, nest site characteristics, nest fate, and the proportion of eggs hatched in three Hawaiian waterbird species. While potential avian predators and other waterbirds did contribute some predation risk, our results showed that mammals had the highest impact on reproductive success for all three species, with the Indian Mongoose responsible for the highest number of nest failures. Vegetation characteristics such as vegetation density were not associated with nesting success for gallinules, coots and stilts, and interactions between predator detections and vegetation were inconclusive. Our results are consistent with previous studies suggesting that the removal of mammals is critical to the nesting success of endangered waterbirds, in combination with habitat management to optimize for preferred nesting characteristics of these three species.

INTRODUCTION

Within island ecosystems globally, invasive predator species are well known as the leading cause of declines and extinctions of island native species (Doherty et al., 2016). Following the introduction of non-native predators on remote islands, native species have experienced precipitous population declines and extinction rates (Dueñas et al., 2021). However, few studies have quantified differential impacts among predator and prey types (Brzeziński et al., 2020).

Species on isolated islands evolved with a reduced suite of predators, and thus may lack antipredator behaviors specific to introduced species (Sih et al., 2010). As a result, following the introduction of non-native predators to islands, many native species have experienced precipitous population declines and accelerated extinction rates (Schlaepfer et al., 2005). Predation rates likely differ among native and invasive predator species, and among impacted native prey species (Dueñas et al., 2021). These differences have important implications for the allocation of management resources to minimize predator impacts, since removal methods vary among predator types. Thus, a better understanding of the mechanisms impacting predation may not only provide insights regarding how predators affect the structure of island communities and demography (Thompson, 2007), but may also improve conservation outcomes through improved management of invasive predators.

Within the avian community, ground-nesting birds are susceptible to predation by a diverse group of native and nonnative predators (Schüttler et al., 2009). Since predation is the leading cause of nest failure in ground-nesting birds (Cox et al., 2012; Reidy & Thompson III, 2013; Ricklefs, 1969), the identification of dominant nest predators is integral to developing optimal conservation strategies (Benson et al., 2010). Different predtors may target different developmental stages, such as the chick and incubation stages, depending on their feeding strategies (De Roos et al., 2008). Further, predator impacts on these different developmental stages may vary in relation to nest-site characteristics and ability of the predator to discover the nest (Chiavacci et al., 2018; Fournier et al., 2021; Thomas E. Martin & Briskie, 2009).

Individual bird species examine habitat to select nest-site characteristics that maximize reproductive success (Ibáñez-álamo et al., 2015; Liu et al., 2021; Vanderwerf, 2012). Nest site

characteristics such as vegetation height and vegetation density may conceal nests from some predator types, but may also provide cover for other species of ground-based predators to approach the nest without triggering defensive measures (T.E. Martin, 1993; Schüttler et al., 2009). For example, mammals find their prey by olfactory, auditory, and visual cues (Whelan & Dilger, 1994), and avian predators largely locate their prey visually (Martin, 1993). Water may reduce mammalian access to nests in wetlands, if mammalian predators are hesitant to swim or if the scent of the nest is reduced by the water (Martin, 1993).

Predation is a major cause of nest failure in three species of Hawaiian waterbirds, the Hawaiian Stilt (Aeʻo; *Himantopus mexicanus knudseni*), Hawaiian Coot (ʻAlae keʻokeʻo; *Fulica alai*), and Hawaiian Gallinule (ʻalae ʻula ; *Gallinula galeata sandvicensis*) (USFWS, 2011). Each of these species differs in their preferred nest site characteristics (Griffin et al., 1989), making them an excellent case study in which to examine the relationships among predator types, nest-site characteristics, and nesting success. Hawaiian Gallinule nests are built in areas with dense aquatic vegetation, and formed from emergent plant species such as Pickleweed (*Batis* maritima) and California Grass (*Urochloa mutica*) which are bent over to form a platform (Myers & F., 1924). Hawaiian Stilt nests are built on exposed mudflats with low growing vegetation. Nests are built from grass stems and rocks for nesting material and on islands in freshwater or brackish ponds. Hawaiian Coot nests are built on platforms of aquatic vegetation floating in open water or in clumps of vegetation on shorlines (Engilis & Pratt, 1993). Due to these differences in nest-site preferences, the nests of these three species would be expected to differ in their vulnerability to various predator types.

Prior to the arrival of humans, Hawaiian waterbirds only had a variety of avian predators such as owls, sea eagles, and herons, as the Hawaiian Islands lacked native amphbians, reptiles, and mammals other than the Hawaiian Hoary Bat (Duffy & Capece, 2012; Hays & Conant, 2007; Shiels et al., 2014; Wehr et al., 2018). Thus, we would expect that Hawaiian waterbirds evolved defenses specific to avian predators, but potentially lack defenses specific to mammals, reptiles, or amphibians. Today they face a variety of potential mammalian, avian and amphibian predators, most of which were introduced within the last 200 years, including Feral Dogs (*Canis familiaris*), Feral Cats (*Felis silvestris*), Small Indian Mongooses (*Herpestes auropunctatus*), Rats (*Rattus spp*.), Cattle Egrets (*Bulbulcus ibis*), ʻAukuʻu (Black-crowned Night Heron,

Nycticorax nycticorax hoactli), Barn Owls (*Tyto alba*), Pueo (Hawaiian Short- eared Owl, *Asio flammeus sandwichensis*), Bullfrogs (*Rana catesbeiana*) (J. , G. Underwood et al., 2014; J. G. Underwood et al., 2013). There are other rare nest predators, including Common Mynah (*Acridotheres tristis*), that are known to be egg predators in Hawai‘i (Myers & F., 1924).

Of these, invasive mammals may have the highest impact on Hawaiian birds (Christensen et al., 2021; Harmon et al., 2021, Katayama et al., in prep), since these birds evolved in the absence of native mammalian predators. Polynesian rats (*Rattus exulans*) were brought to the Hawaiian Islands by Polynesian voyagers approximately 1000 years ago, with two additional species (Norway Rat, Black Rat) brought on European ships approximately 200 years ago (Shiels et al., 2014). Domestic cats were brought to Hawai‘i on European ships and established feral populations throughout the islands (Duffy & Capece, 2012). Small Indian Mongooses were introduced to Hawai‘i as biocontrol for rats that were affecting sugar cane production (Hays & Conant, 2007). While all these species have been documented as invasive predators of native avifauna in Hawai‘i (Reed et al., 2012), the relative impact of these predator species on these three Hawaiian waterbirds is still unknown.

Studies of nesting success and the parameters that influence it are critical to understanding the demographic parameters in bird populations (Cooper et al., 2019; Whitehead et al., 2008). Previous studies have found mixed results regarding the benefits of nest concealment (Hu et al., 2017), potentially due to varying predator activity during the nesting season (Remeš, 2005; Smith et al., 2018). To address this apparent research gap regarding differential impacts of potential predator species on ground-nesting species based on their nest-site characteristics, we utilized a combination of visual nest checks and motion-activated cameras to determine nest fate and potential predator detections at the nest in three waterbirds whose relatives commonly co-occur in wetlands globally: ‘Alae ke‘oke‘o (Hawaiian Coot; *Fulica alai),* Ae‘o (Hawaiian Stilt; *Himantopus mexicanus knudseni*), ‘Alae ‘ula (Hawaiian Gallinule; *Gallinula galeata sandvicensis*). As these waterbirds differ in their preferred nesting habitat, they provide an optimal opportunity to explore the relationship between nest-site characteristics, predation risk by different predator types, and nesting success.

METHODS

Study Species & Site

These three species co-occur on two islands, O‘ahu and Kaua‘i, but only a few wetlands on each of these islands support robust populations of all three species. This study was conducted at the largest wetland complex on O‘ahu, Kawainui-Hāmākua wetland complex, on the island of O‘ahu, Hawai‘i (Figure 1, 21.43272°N, -157.75211°W). Kawainui and Hāmākua Marsh State Wildlife Sanctuaries provide core habitat for waterbirds and shorebirds (U.S. Fish and Wildlife Service, 2011). Both wetlands are managed by the Division of Forestry and Wildlife (DOFAW) of the Hawai‘i State Department of Land and Natural Resources.

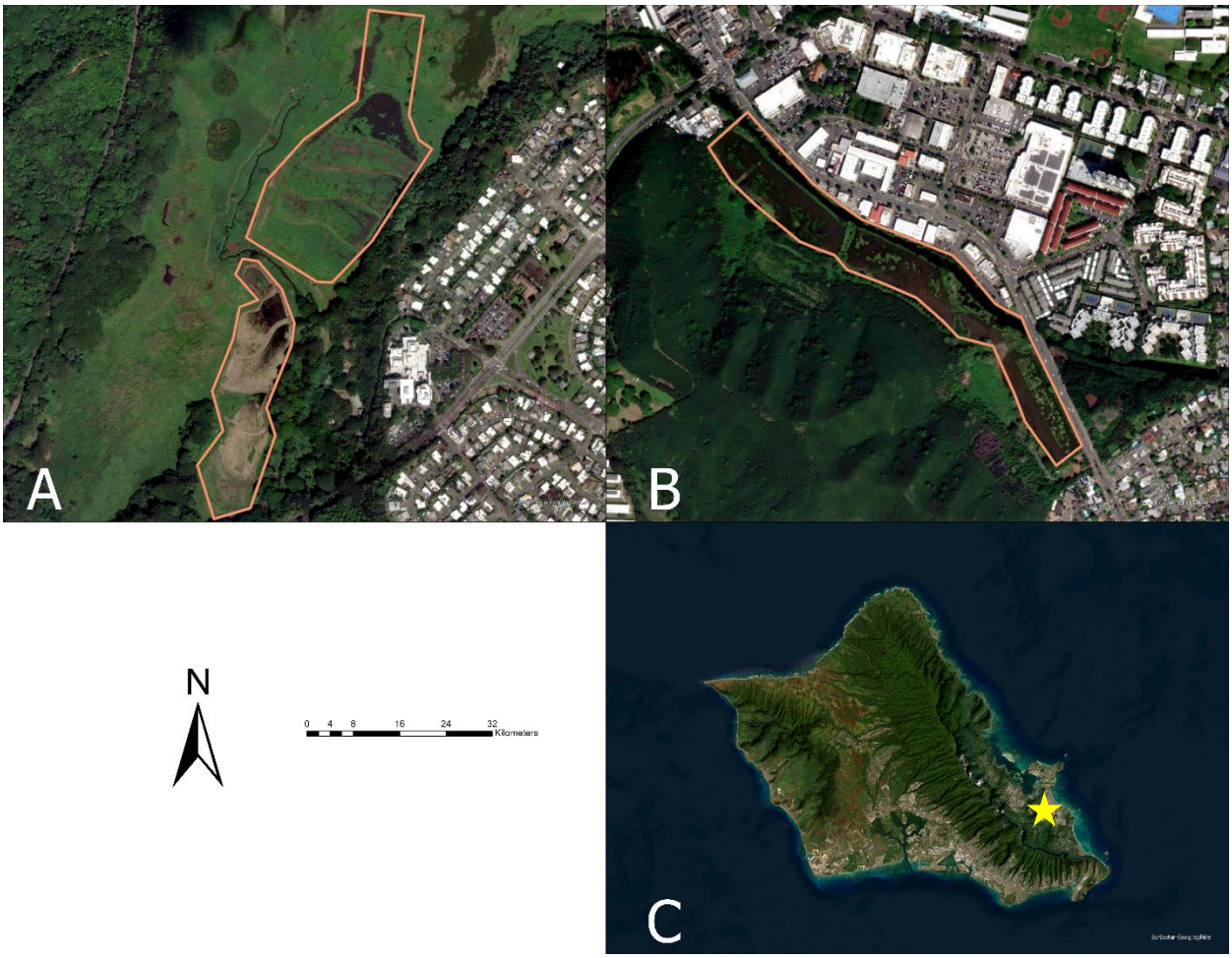

Figure1. Map of Kawainui (A); Hāmākua Marsh (B) State Wildlife Sanctuary; (C) Island of O‘ahu, Hawai‘i (C).

Kawainui is comprised of eleven interior terraced cells (0.6 – 4.1 acres each). The pond system is bisected by the Maunawili stream, dividing the North Ponds into 5 interior cells and the South Ponds into 6 interior cells. Each interior cell was constructed in an irregular mosaic pattern, and water is supplied through rainfall and periodic flooding of Maunawili Stream Vegetation management of invasive species takes place from September-March, with the main goal of eliminating growth of invasive Californian Grass (*Urochloa mutica*) and promoting growth of wetland plants.

Hāmākua Marsh is a wetland of approximately 23 acres and is comprised of a complex of basins. The complex is divided by four different basins (A: 4.6 acres; B: 9.5 acres; C: 6 acres; D: 3.2 acres), and each basin is comprised of open water, vegetation and mudflat. Both wetlands have active vegetation management to promote nesting habitat for Hawaiian waterbirds (Price & Harmon, 2019). For example, vegetation removal of invasive species such as pickleweed (*Batis maritima*) takes place from September to March to increase mudflats for stilt nesting.

Data Collection

Nest Surveys. For the January 2022 – August 2023 breeding seasons, we conducted routine weekly surveys with Division of Forestry & Wildlife (DOFAW) personnel in Kawainui and Hāmākua Marshes to locate nests of stilts, gallinules, and coots. Within each wetland unit, surveys were conducted by walking parallel, meandering transects 10 m apart throughout the wetland. Upon the discovery of a nest the latitude and longitude were recorded, along with vegetation species, percent of vegetation cover, vegetation height, and vegetation density within two meters of the nest. To avoid increased predation risk to the nest, we minimized the amount of time spent collecting data at the nest.

Nest Monitoring. Motion-activated cameras were set up by DOFAW personnel under their permits and protocols (1984 Section 6 Cooperative Agreement with the USFWS) and data were shared with UH personnel. Under their protocol, a Spypoint Solar Dark passive infrared camera (GG Telecom; Victoriaville, Canada) was positioned 2m from each nest, mounted on a 1” x 1” wooden post or metal t-post, pointing down toward the nest, and secured with a camera strap or bolt, by DOFAW personnel once the egg laying period had ended to avoid disturbance of the

laying adults. Motion-activated game cameras were used to monitor nesting success and predation events (Christensen et al., 2021; Ribeiro-Silva et al., 2018; Waterbirds et al., 2013). Spypoint Solar Dark camera traps were placed pointing towards the nest and were programmed to take two successive images immediately upon triggering (trigger speed = 0.07 s, recovery speed = 0.3 s). Each camera was set and programmed for high sensitivity to take 3 photos each trigger. Cameras were checked weekly for battery replacement and data card retrieval and each camera was left up for 14 days post-hatch and then removed immediately after the period ended.

Vegetation Measurements. The vegetation density was measured by visually estimating the percent of visual obstruction in the pole (VOR) by vegetation at four different segments (Journal & Jul, 1970). We counted the number of segments obstructed by the pole to determine the percent visual obstruction. The vegetation height, vegetation cover and percentage of VOR were measured in four different cardinal directions at random points two meters distance from the nest. We then averaged the values for vegetation density and height among the four cardinal directions for subsequent analyses (Chiavacci et al., 2018; Journal & Jul, 1970).

Permitted activities for Hawaiian Stilts were conducted under permits held by the Price lab (Bird Banding Lab permit no. 24339 and 24137 ; United Fish & Wildlife Service Recovery Permit no. TE-25955C-3; Hawai‘i Department of Forestry and Wildlife Protected Wildlife Scientific Collecting no WL23-04 and WL20-05; University of Hawai‘i Institutional Animal Care and Use Committee protocol no. 172733-5).

Data Analyses

For each nest camera, photos were reviewed to determine if the nest was successful (hatched) or unsuccessful (predated, flooded or abandoned). A nest was considered successful if at least one egg hatched and unsuccessful if no eggs hatched. The following criteria were used to determine if a nest was depredated: (1) a depredation event was captured on camera; (2) eggs were missing from the nest prior to the anticipated hatch date and predator tracks or scat were present at or near the nest; (3) destroyed eggs were discovered inside or near the nest (Cuervo, 2005; DOFAW 2020, Harmon et al., 2021). Based on the nest camera photos and the nest visits, we also recorded clutch size and the number of eggs hatched for each nest.

Camera photos were sorted and analyzed for predator detections using Mega Detector and Timelapse software. Mega Detector (Vélez et al., 2023) was used to detect photos of interest such as those with animals, people, and vehicles. MegaDetector is a free machine-learning model created by Microsoft AI for object detection that helps streamline image processing by eliminating false triggers (Fennell et al., 2022). Image results were incorporated into Timelapse (Greenberg et al., 2019) for image processing. To validate results, we reviewed a subset of images (n=1,163,613) that were ranked by MegaDetector between a confidence of interval of 0.50-1.00 to confirm that they contained detections of animals. We additionally reviewed a subset of images (n=100,000) with a confidence interval of 0.00-0.49 to validate that they did not contain detections of animals. Images containing humans and the remaining image set between 0-0.50 confidence interval were discarded. Photos were coded as '0' or '1'; '0' was assigned when a predator was not observed, and '1' was assigned when a predator was detected. Upon detecting a predator, the predator type was identified when possible.

All analyses were conducted in the program R 4.1.0 (R Core Development Team, 2021). We used a general linear model (GLM) to examine if nest site characteristics and predator detections at the nest were related to the nesting success and proportion of eggs hatched for each of the three waterbird species. First, we used a logistic binomial regression to examine: (1) the relationship between predator detections at the nest with nest fate of each species as a response variable; and (2) the relationship between vegetation parameters and nest fate. For all our models, predator species were grouped in three different taxonomic groups: (1) mammals (rats, cats, Indian Mongoose), (2) avian predators (Cattle Egret, Black-crowned Night Heron), (3) other waterbirds (ducks, stilts, gallinules, coots), due to the effect of small sample sizes and correlation among individual species included in the same taxonomic group (Figure A.10.1 Appendix B). The first model consisted of three explanatory variables: detections of (1) mammals, (2) avian predators, and (3) others waterbirds (Chiavacci et al., 2018). The second model consisted of two explanatory variables: (1) vegetation density, and (2) vegetation height.

We also used a linear regression analysis to examine the: (1) the relationship between predators detected at the nest and the proportion of eggs hatched as a response variable; (2) the relationship between mammal detections at the nest and vegetation variables with the proportion of eggs hatched as a response variable; (3) the relationship between mammal species detected at

the nest with the proportion of eggs hatched as a response variable. The first model consisted of three explanatory variables: detections of (1) mammals, (2) avian predators, (3) other waterbirds. The second model consisted of three explanatory variables: (1) mammals, (2) vegetation density, and (3) vegetation height. The third model consisted of three explanatory variables: detections of (1) mongoose, (2) cats, (3) rats. For each model, we created a set of candidate models *a priori* based on the nest-fate and the proportion of eggs hatched. Models were ranked using Akaike's information criterion corrected for small sample sizes to determine the probability that each model would be the best among the model set. (AICc; Burnham & Anderson, 2002; Korner-Nievergelt et al., 2015). The analysis only included days when the date of nest discovery was monitored with cameras (Chiavacci et al., 2018).

Only nests that were active upon first encounter were used for analyses. All nests that were found with "unknown" and "found abandoned" fates were excluded from the analysis. This included nests that were already abandoned when they were found and nests that had an unknown fate due to a camera malfunction, as we could not identify if the nests found were predated and/or abandoned before found or if the remaining eggs were abandoned or predated.

RESULTS

Data were collected for 65 Hawaiian Gallinule nests, 49 Hawaiian Stilt nests and 20 Hawaiian Coot nests at Hāmākua (n=85) and Kawainui (n=49) from January 2022 – August 2023 breeding seasons. Reproductive success metrics were recorded and calculated at the two nesting sites (Table 1). A total of 48% of Hawaiian Gallinule nests (n=31), 49% of Hawaiian Stilt nests (n=24) and 55% of Hawaiian Coot nests (n=11) hatched at least one chick. A total of 52% of Hawaiian Gallinule nests (n=34), 51% of Hawaiian Stilt nests (n=25) and 45% of Hawaiian Coot nests (n=9) failed.

Table 1. Summary of all nests found and monitored during the study period. Hawaiian Stilt, Hawaiian Gallinule and Hawaiian Coot reproductive success metrics recorded and calculated at the two nesting sites on the island of O'ahu, Hawai'i in the 2022 and 2023 breeding seasons. The total number of nests n (total nests excluding nests found abandoned or with unknown fate) and N/A indicates a value that was not applicable and/or could not be calculated.

Species	Site	Nests (n)	# Eggs Laid	# Eggs Hatched	Nesting Success	Hatching Success	Fledgling Success

Stilts							
Year 2022	Hāmakuā	15	45	28	53%	62%	54%
	Kawainui	2	8	6	100%	75%	67%
Year 2023	Hāmakuā	21	79	23	33%	29%	39%
	Kawainui	11	39	18	64%	46%	6%
Gallinules							
Year 2022	Hāmakuā	6	26	11	50%	42%	18%
	Kawainui	11	55	16	36%	21%	0%
Year 2023	Hāmakuā	32	258	93	50%	39%	1%
	Kawainui	16	167	64	50%	38%	2%
Coots							
Year 2022	Hāmakuā	2	4	3	50%	75%	0%
	Kawainui	3	14	3	66%	21%	0%
Year 2023	Hāmakuā	8	34	3	25%	32%	0%
	Kawainui	7	49	24	86%	49%	0%
Total		**134**	**778**	**293**	Mean 55%	Mean 44%	Mean 16%

Among the failed nests, a total of 17% of nests of Hawaiian Gallinules (n=11), 27% of Hawaiian Stilts (n=13) and 5% of Hawaiian Coots (n=1) failed due to predation. Within the failed nests, 18% of Hawaiian Gallinule nest (n=12), 2% of Hawaiian Stilts (n=1) and 5% of Hawaiian Coots nests (n=1) failed due to flooding events. Furthermore, 11% of Hawaiian Gallinule nests (n=7), 14% Hawaiian Stilt nests (n=7) and 25% of Hawaiian Coot nests (n=5) were abandoned. The cause of failure was unknown for 6% of Hawaiian Gallinule nests (n=4), 8% of Hawaiian Stilt nests (n=4) and 10% of Hawaiian Coot nests (n=2) (Table 2). Of the 28 nests with evidence of egg destruction, we found evidence of nest depredation by Indian mongoose (n=15; 10 stilts, 1 coot and 4 gallinules), and egg destruction by Hawaiian Gallinules (n=3, 2 other gallinule nests and 1 on a stilt nest), and a Hawaiian Coot (n=1 (on stilt nest)). We also found 3 suspected self-egg destructions by Hawaiian Gallinules of their own nests. For the remaining 6 nests (3 stilts and 3 gallinules) in which eggs were destroyed, we were unable to determine the cause due to camera battery failure and/or camera malfunction.

Table 2. Hawaiian Stilt, Hawaiian Gallinule and Hawaiian Coot summary of all failed nests at the two nesting sites on the island of O'ahu, Hawai'i in the 2022 and 2023 breeding seasons. The totals number of nests (n=68) and outcomes: Predated, Abandoned, Flooded and/or Unknown.

Species	Site	Nests (n)	Predated	Abandoned	Flooded	Unknown
Stilts						
Year 2022	Hāmakuā	7	43%	14%	0 (0%)	43%
	Kawainui	0	0 (0%)	0 (0%)	0 (0)%	0 (0%)
Year 2023	Hāmakuā	14	72%	21%	0 (0%)	7%
	Kawainui	4	25%	75%	0 (0%)	0 (0%)
Gallinules						
Year 2022	Hāmakuā	3	33%	67%	0 (0%)	0 (0%)
	Kawainui	7	43%	0 (0%)	0 (0%)	57%
Year 2023	Hāmakuā	16	31%	25%	44%	0 (0%)
	Kawainui	8	25%	13%	63%	0 (0%)
Coots						
Year 2022	Hāmakuā	1	0 (0%)	0 (0%)	0 (0%)	1 (100%)
	Kawainui	1	0 (0%)	1 (100%)	0 (0%)	0 (0%)
Year 2023	Hāmakuā	6	17%	66%	0 (0%)	17%
	Kawainui	1	0 (0%)	0 (0%)	0 (0%)	100%
Total		**68**	**26 (38%)**	**19 (28%)**	**12 (18%)**	**11 (16%)**

Of 65 Hawaiian Gallinules nests discovered across both years, 46% (n =30) were successful (hatched at least one chick), 19% (n = 12) failed due to depredation, 18% (n = 12) failed due to flooding, 11% (n=7) failed due abandonment, and 6% (n = 4) had unknown fates. Of 49 Hawaiian Stilts nests discovered in both nesting sites, 49% (n = 24) hatched at least one chick, 27% (n = 13) failed due to predation, 2% (n = 1) failed due to flooding, 14% (n = 7) failed due to abandonment, and 8% (n = 4) had unknown fates. Of 20 Hawaiian Coots nests discovered in Hāmākua and Kawainui, 55% (n = 11) hatched at least one chick, 5% (n =1) failed due to depredation, 5 % (n=1) failed due to flooding, 25% (n=5) failed due abandonment, 10% (n = 2) the fates were unknown (see Appendix Table 1). Of the 26 nests that were predated (Table 2) , we confirmed 15 nests were predated by mongoose, 2 by conspecific (gallinules) and 1 heterospecific predation event (gallinule on a stilt nest).

In the model selection to assess the relationships of predator detections at nests during the nesting period on the probability of nesting success, the best performing model with the lowest AICc value and the largest weights were the mammal detections on gallinules and coots and the global model for stilts (Figure 2, Appendix A Figure 1).

Table 3. Model selection of predator detections at nests of Hawaiian Stilts (n=49), Hawaiian Gallinules (n=66) and Hawaiian Coots (n=19) in regard to nest fate at Hāmakuā and Kawainui. Models were ranked using Akaike's Information Criterion corrected for small sample sizes (AICc) and reported as the change in AICc value from the best-performing model (ΔAICc). K is the number of model parameters in each model. *wi* is the Akaike model weight *(Hawaiian Stilts: R^2 = 0.27, SE=1.59, P = 0.9; Hawaiian Gallinules: R^2 = 0.03, SE = 0.06, P = 0.2, Hawaiian Coots: R^2 = 0.12, SE = 1.9, P = 0.9).*

Stilts	K	AICc	ΔAICc	*wi*	LL
Mammals + Avian Predators+ Other Waterbirds*	4	58	0	0.846	-24.535
Mammals	2	61.6	3.65	0.137	-28.682
Avian Predators	2	66.1	8.11	0.015	-30.913
Null	1	70	12.01	0.002	-33.954
Other Waterbirds	2	72.2	14.19	0.001	-33.953

Gallinules	K	AICc	ΔAICc	*wi*	LL
Mammals*	2	92.1	0	0.437	-43.955
Null	1	92.3	1.21	0.238	-45.626
Avian Predators	2	94.6	2.48	0.126	-45.195
Other Waterbirds	2	94.7	2.6	0.119	-45.253
Mammals + Avian Predators+ Other Waterbirds	4	95.5	3.41	0.079	-43.429

Coots	K	AICc	ΔAICc	*wi*	LL
Mammals*	2	27.8	0	0.428	-11.517
Null	1	28.5	0.74	0.296	-13.143
Avian Predators	2	29.7	1.89	0.166	-12.463
Other Waterbirds	2	31	3.21	0.086	-13.124
Mammals + Avian Predators+ Other Waterbirds	4	33.6	5.82	0.023	-11.376

For stilt, gallinule and coot nests, the higher detections of mammals at the nest, the lower the probability of nesting success (Appendix Figure 1).

Furthermore, for stilt nests, mammal detections had the strongest relationship with the proportion of eggs hatched; the higher the number of mammal detections, the lower the proportion of eggs hatched. The best fit model for coot and gallinule nests was the null model,

however mammal detections also had the strongest relationship with the proportion of eggs hatched for gallinule nests; the higher the number of mammals detected, the lower the proportion of eggs hatched (Figures 3, Appendix A Figure 2).

Table 4. Model selection of predator detections at Hawaiian Stilt nests (n=49), Hawaiian Gallinule nests (n=66) and Hawaiian Coot nests (n=19) in regard to the proportion of eggs hatched at Hāmakuā and Kawainui. Models were ranked using Akaike's Information Criterion corrected for small sample size (AICc) and reported as the change in AICc value from the best-performing model (ΔAICc). K is the number of model parameters in each model. *wi* is the Akaike model weight. *(Hawaiian Stilts: R^2 = 0.05, SE = 0.007, P = 0.08; Hawaiian Gallinules: R^2 = 0.3, SE = 0.04, P = 4.99e-09, Hawaiian Coots: R^2 = 0.3, SE = 0.1, P = 0.003).*

Stilts	K	AICc	ΔAICc	*wi*	LL
Mammals*	3	59.6	0	0.48	-26.51
Null	2	60.6	1.05	0.284	-28.173
Avian Predators	3	62.8	3.24	0.095	-28.133
Other Waterbirds	3	62.8	3.26	0.094	-28.141
Mammals + Avian Predators+ Other Waterbirds	5	64.2	4.62	0.047	-26.395

Gallinules	K	AICc	ΔAICc	*wi*	LL
Null*	2	70.7	0	0.336	-33.2688
Mammals	3	70.8	0.09	0.321	-32.215
Avian Predators	3	72.3	1.61	0.15	-32.976
Other Waterbirds	3	72.4	1.65	0.147	-32.996
Mammals + Avian Predators+ Other Waterbirds	5	74.7	3.99	0.046	-31.857

Coots	K	AICc	ΔAICc	*wi*	LL
Null*	2	26.1	0	0.472	-10.67
Mammals	3	27.8	1.71	0.2	-10.101
Other Waterbirds	3	28.2	2.1	0.165	-10.297
Avian Predators	3	28.5	2.37	0.144	-10.431
Mammals + Avian Predators + Other Waterbirds	5	32.5	6.43	0.019	-8.951

Table 5. Model selection of detections of three mammals at Hawaiian waterbird nests (n=134) in regard to the proportion of eggs hatched at Hāmakuā and Kawainui. Models were ranked using Akaike's Information Criterion corrected for small sample sizes (AICc) and reported as the change in AICc value from the best-performing model (ΔAICc). K is the number of model parameters in each model. *wi* is the Akaike model weight. *(Mongoose: R^2 = 0.02, SE= 0.004, P = 0.03)*

Model Parameters	K	AICc	ΔAICc	*wi*	LL
Mongoose*	3	146.6	0	0.578	-70.208

Rat	3	149.1	2.45	0.17	-71.434
Mongoose + Rat + Cat	5	149.3	2.68	0.151	-69.406
Cat	3	150.1	3.48	0.101	-71.949
Null	1	218.1	71.52	0	-108.044

Of the mammals detected during the study (mongoose, rat, cat), mongoose detections had the strongest relationship with the proportion of eggs hatched (Mammals *P-value* = 0.04 ; Figure 7). The higher the number of mongoose detections, the lower the proportion of eggs hatched (Appendix A Figure 4).

For stilt, gallinule and coot nests, there was no relationship between predator detections at the nest and the vegetation density or vegetation height at the nest. For stilt nests, mammal detections had the strongest relationship with nest fate considering vegetation in the model - the higher the number of mammal detections, the lower the probability of nesting success. The best fit model for gallinules was the global model, and for coots the null model (Figure 5).

Table 6. Model selection of mammal detections and vegetation density of Hawaiian Stilts nests (n=49), Hawaiian Gallinules (n=66) and Hawaiian Coots (n=19) in regards nesting success at Hāmakuā and Kawainui. Models were ranked using Akaike's Information Criterion corrected for small sample sizes (AICc) and reported as the change in AICc value from the best-performing model (ΔAICc). K is the number of model parameters in each model. *wi* is the Akaike model weight. Given the correlation between vegetation height and vegetation density, only vegetation density was included in subsequent analysis. *(Hawaiian Stilts: R^2 = 0.27, SE = 1.59, P = 0.9; Hawaiian Gallinules: R^2 = 0.01, SE = 1.31, P = 0.9, Hawaiian Coots: R^2 = 0.4, SE = 0.5, P = 0.7).*

Stilts	K	AICc	ΔAICc	*wi*	LL
Mammals *	2	38.7	0	0.748	-17.148
Mammals + Vegetation Density	3	41.1	2.44	0.221	-17.145
Null	1	46.0	7.28	0.020	-21.930
Vegetation Density	2	47.0	8.32	0.012	-21.309

Gallinules	K	AICc	ΔAICc	*wi*	LL
Mammals + Vegetation Density*	3	63.1	0	0.726	-28.282
Mammals	2	66.4	3.35	0.136	-31.092
Vegetation Density	2	66.6	3.49	0.127	-31.163
Null	1	71.3	8.23	0.012	-34.617

Coots	K	AICc	ΔAICc	*wi*	LL
Null*	1	23	0	0.486	-10.364

Mammals	2	24.1	1.09	0.282	-9.561
Vegetation Density	2	25.2	2.12	0.169	-10.077
Mammals + Vegetation Density	3	27.1	4.07	0.063	-9.464

DISCUSSION

While concerns about invasive mammals are well documented (Carpenter et al., 2018; Courchamp et al., 2003; Cramb & Pimental, 2021; Dueñas et al., 2021; Garcia-Heras et al., 2024; Hays & Conant, 2007; Oppel et al., 2014), the impacts of these invasive mammals relative to other invasive taxonomic groups and native predators has received less attention (Ruland & Jeschke, 2020). To our knowledge, this is the first study to compare the relative impacts of potential native and invasive predators on three endangered Hawaiian waterbirds, Hawaiian Stilts (*Himantopus mexicanus knudseni*), Hawaiian Gallinules (*Gallinula galeata sandvicensis*) and Hawaiian Coots (*Fulica alai*). Despite detections of many potential nest predators, including amphibians, birds, mammals, and reptiles, only mammals and birds were confirmed to predate nests. Of these, mammals carried two to three times more weight than avian predators in models that examined the relationship between predator detections and the proportion of eggs hatched. Of the mammals, the Small Indian mongoose was the largest contributors to nest failure in all three waterbird species. Destruction of conspecific and/or heterospecific eggs by Hawaiian Gallinules and Hawaiian Coots was observed in this study, but additional studies of marked adult populations are needed to determine the frequency of this occurrence. Egg predation by native (Black-crowned Night Heron) and nonnative (Cattle Egrets) birds was not observed during this study but has been documented in previous studies of Hawaiian Stilts (Harmon et al. 2021; Katayama et al., under review).

Our results are consistent with global studies documenting the impact of invasive mammals such as cats, rats, and mongooses on native species (Ferreras & Macdonald, 1999; Louppe et al., 2020; Schüttler et al., 2009; Yagihashi et al., 2021). Removal of invasive mammalian predators is crucial to improve waterbird population growth and achieve recovery goals for these endangered species. Furthermore, our results suggest that among invasive mammalian predators, the Indian Mongoose poses a major threat to at least two Hawaiian waterbird species. This further highlights the need for increased attention to this broadly

introduced species and its global impacts on native birds, amphibians, and reptiles (Engeman et al., 2006; Komine et al., 2020; van Veen & Wilson, 2017). Although not detected in this study, cats were observed predating eggs in a previous study (Katayama et al., in review), suggesting they may impact ground-nesting waterbirds at all life history stages, and highlighting the importance of their removal in sensitive areas.

While mammals posed the greatest threat to nesting success, avian predators and/or other waterbirds also contributed to nest failure, similar to other waterbird species (Bruni et al., 2013). Cattle Egrets, like invasive mammals, have been introduced globally by humans to aid in pest control (Bradley et al., 2019; Gurevitch & Padilla, 2004; Mooney & Cleland, 2001). In the Hawaiian Islands, Cattle Egrets have officially been determined to be a pest species, allowing for removal in areas where they are harming endangered species. Native predatory birds such as Black-crowned Night Herons and Short-eared Owls consume eggs and chicks and were historically part of the wetland community (Garcia-Heras et al. 2024, Katayama et al., under review). Other heterospecific and conspecific waterbirds may destroy eggs, as was observed in this study, due to competition for resources (Brussee et al., 2016; Šálek et al., 2022). Previous studies on the diet of the Black Crowned Night Heron suggest this species can be an egg predator (Quiroga et al., 2013). Furthermore, a few studies have reported amphibians (cane toad and bullfrogs) eating birds eggs (Beckmann & Shine, 2012), suggesting that further research needs to be done examining predator diets, to better understand their feeding strategies and behavior towards this waterbird species.

Adult stilts were frequently observed using anti-predator behaviors and aggressive flight toward potential predators approaching the nest, as has been observed in other studies (Harmon et al., 2021; A. Sordahl, n.d.; Thx A Sordahl, 1996; Pierce & Lake, 1986), such as wing displaying, mobbing, and “dive-bombing” (Harmon et al., 2021). Defensive behaviors toward Red-eared Sliders (*Trachemys scripta*), Bullfrogs (*Rana catesbeiana*), Cane Toads (*Rhinella marina*) and Hybrid Koloa Maoli (*Anas wyvilliana*) were documented by photos, with up to 10 stilt adults participating in mobbing events against Red-eared Slider turtle. These behaviors may have been more effective at deterring potential avian predators than mammalian predators.

Gallinules and coots utilized nest sites with taller and more dense vegetation, in contrast to stilts, potentially obscuring the nest from visual discovery but also potentially allowing predators to approach closer to the nest before parents initiated defensive behaviors. Of all potential predator types, mammals had the biggest impact on nesting success for coots and gallinules. This suggests that dense vegetation is somewhat effective at obscuring nests from avian predators (Thomas E Martin, 2017; Schüttler et al., 2009), but is less effective for mammals, which have stronger olfactory capabilities (Louppe et al., 2020; Schüttler et al., 2009; Yagihashi et al., 2021). Previous studies suggest that dense vegetation and the amount of open water at the wetland scale may contribute to coot nesting success (Austin & Buhl, 2011; Fournier et al., 2021) and the risk of predation (Schmidt et al., 2023). However, further studies should examine the influence of parental activity during incubation and the relationship with mongoose abundance and activity patterns among these three species on the nesting survival probability during the nesting stage.

Clutch sizes of gallinules were substantially higher in the second year of our study, correlating with an increase in precipitation and available water in the wetlands. Interestingly, other studies have demonstrated that perceived predation risk may increase the frequency of intraspecific brood parasitism, increasing clutch sizes (McRae, 1997). All three of the species in our study may engage in “egg dumping”, or brood parasitism, laying their eggs in other conspecific nests, as this has been observed in Hawaiian Stilts (Dibbens-Young et al. 2021) as well as other species of coots and gallinules (McRae, 2011). In this study, we were unable to determine whether the laying adult was part of the parental pair or a nearby conspecific, as most adults were not banded, but future studies should examine this phenomenon in this species in the context of predation risk.

Nest abandonment was the second cause of nest failure in this study, followed by flooding events (Table 2). Past studies suggest that nest abandonment can occur due to mortality of an attending adult, perceived predation risk, or disturbance by predators (Roche et al., 2010). As waterbirds can re-nest following a failed nesting attempt (Reed and Rees, 2019; van Rees et al. 2020, Garrettson et al., 2011), when encountering a potential predator of adult birds, the parent may be more likely to abandon the nest to ensure the potential for future nesting attempts. In this study, one nest was abandoned after the suspected predation of an adult by a raptor

(Image 8, Appendix B). Further research is needed to examine parental behavior, nest abandonment, and causes of adult mortality, alongside environmental factors such as water levels that may influence risk of predation and abandonment (Lima, 2009).

For gallinules, nests with higher vegetation density hatched more eggs. In contrast, for coots, nests with shorter vegetation were more successful. Nest site characteristics such as vegetation height and vegetation density may conceal nests from some predator types, but may also provide cover for other species of ground-based predators (Martin, 1993; Schüttler et al., 2009). Mongoose were detected at a total of 15 nests (stilts=10, gallinules=4, coots=1). As mammals such as mongoose find their prey by olfactory cues (Whelan & Dilger, 1994), nest site characteristics may not conceal nests from mammals. However, further studies should examine the influence of habitat characteristics on mongoose abundance and activity patterns (Louppe et al., 2020).

Water may reduce access to nests if mammalian predators are hesitant to swim or if the scent of the nest is reduced by the water (Martin, 1993), and this may be why mongoose had a lower number of detections at the coot nests. Previous studies suggest that water levels and depth may alter the predation risk by the predator community on these ecosystems (Clark et al., 2003; Hoover, 2006), improving overall the nesting survival of waterbirds (Schmidt et al., 2023). Nest concealment has been linked to risk from avian predators and water depth with a decreased risk from terrestrial land-based predators (Ellis et al., 2020; Hoover, 2006). A reduction in water levels during the peak of nesting seasons may increase the access to nests by mammalian predators (The et al., 2008). As water depth has been found to be an important predictor of nest predation (Schmidt et al., 2023), future studies should focus on how water level manipulation across the nesting season may influence the nesting success and predation risk by these different predators impacts on these three endangered Hawaiian waterbirds during their nesting stage.

Our study is the first to quantitatively compare the potential impacts of nest predators on nest-site selection and nesting success in three Hawaiian waterbirds. While many potential predator types were detected at nests, mammals posed the greatest threat to nesting success, with the Indian Mongoose responsible for the largest number of nest failures. Avian predators and other waterbirds also contributed to nest failure. Currently, the two major actions for conserving waterbirds are predator control and habitat management. This study suggests that a predator

control strategy that eliminates invasive mammals from waterbird nesting habitat is critical to recovering all three endangered waterbirds. While the preferred nest-site characteristics differ among species, and for some species are associated with nesting success, we did not detect strong relationships between predation risk and vegetation at the nest. Similar to previous studies, this study suggests that in combination with an effective predator control program, the creation of highly heterogeneous habitat with interspersed vegetation, bare ground, and water may be key to maximizing co-occurring nesting habitat for these three endangered waterbirds.

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Chapter 2: Does nest-site selection influence chick fledging success in a precocial species? Habitat characteristics, predators, and daily chick survival of Hawaiian Stilts (*Himantopus mexicanus knudseni*), Hawaiian Gallinules (*Gallinula galeata sandvicensis*), and Hawaiian Coots (*Fulica alai*).

ABSTRACT

Precocial species, in which chicks leave the nest soon after hatching, should select nest sites based on factors that lead to both successful nests and high survival rates in chicks. Given that threats vary between the two stages, there may be tradeoffs in habitat selection between nest-sites that favor hatching success and those that favor fledging success. Previous studies on stilts suggest that causes of chick mortality include starvation, exposure, and predation, with most mortalities occurring within the first week after hatching. However, causes of mortality on gallinule and coot chicks have not been previously studied due to the difficulty of tracking chicks in dense vegetation after hatching. To address this research gap, we utilized a combination of motion-activated cameras and VHF radio tracking to determine the impact of predators and nest site characteristics with chick survival of the three waterbirds. We evaluated: (1) which nest-site characteristics and predator detections at the nest are related to chick survival; and (2) what is the relationship between predator detections, nest site characteristics, and chick fate in the three Hawaiian waterbirds species? Using linear and binomial logistic regression models, we found that vegetation at the nest was not a predictor of predation risk for chicks. Among the few predators detected at the nests during the chick stage, bullfrogs and mongoose appear to be the major predators of waterbirds chicks. We found a 5% daily increase in stilt chick survival between the beginning and end of the nesting season and a 5% daily decrease in gallinule chick survival over the nesting season, suggesting that threats to chick survival may vary over the nesting season. While some predators such as mongoose appear to be a major threat to both eggs and chicks, others, such as bullfrogs, are only a threat during the chick stage. Thus, our results highlight the importance of different types of predator control at different life history stages for all three of these endangered waterbirds.

INTRODUCTION

Precocial species, in which chicks leave the nest soon after hatching (Ricklefs, 1969), should select nest sites based on factors that lead to both successful nests and high survival rates in chicks (Gibson et al., 2016). Adaptive habitat-selection theory suggests that individuals select areas with habitat characteristics that maximize their fitness, or lifetime reproductive success (Orians & Wittenberger, 1991). Given that threats vary between the two stages, there may be tradeoffs in habitat selection between nest-sites that favor hatching success and those that favor fledging success (Chalfoun & Schmidt, 2012).

Nesting success depends on avoiding or defending against predators targeting eggs and adults, as well as minimizing risks from flooding or other habitat disturbances (Polak, 2016; Wilson et al., 2007). Precocial chicks are also vulnerable to predation, and must find adequate food for growth and development or risk starvation (Stantial et al., 2021). A lack of food may lead to slower reactions and increased vulnerability to predators, but movement seeking food may also increase the risk of detection by predators (Schekkerman, Hans; Boele, 2008). Given these risks, precocial species often experience high mortality rates prior to achieving flight, especially in the first days after hatching (Brudney et al., 2013; Colwell et al., 2007; Pakanen et al., 2021; Ricklefs, 1969; Savoca et al., 1976). Chicks surviving to adulthood likely carry genes that help them select habitat characteristics conducive to survival from nesting through recruitment into the breeding population (Chalfoun & Schmidt, 2012).

However, habitat degradation, climate change, invasive predators, and invasive plant species may have altered the compatibility of evolved nest-site selection behaviors with hydrological and biological rhythms in wetlands, reducing reproductive success (Sauve et al., 2021; Şekercioğlu et al., 2012; Steen et al., 2014). Changes in habitat structure can also affect community assemblages of potential competitors and predators (Walk et al., 2010), resulting in rapidly-changing environmental cues that influence the ability of a species to adapt (Guttery et al., 2013). As a result, invasive species and habitat alteration are well-recognized as the key drivers of the extinction of native species globally (Doherty et al., 2016; Mack et al., 2000; Szabo et al., 2012). Thus, an important research priority for endemic island bird species is the identification of habitat characteristics that promote the survival and reproduction of individuals

within a population (Donovan & Flather, 2002). However, few studies have examined habitat characteristics that promote fledging success during both the nesting and chick development stages. For precocial species, this could be important as habitat requirements and causes of mortality may differ between the nesting and chick stages (Bloom et al., 2013).

The Hawaiian Islands provide an excellent system in which to examine the relationship between nest-site selection and fledging success in the context of a changing environment. Hawaiian waterbirds have been particularly impacted over the last 200 years, since they exist at the confluence of freshwater, marine, and terrestrial systems. In the 1800-1900s freshwater was diverted away from wetlands to benefit foreign businessmen through plantation agriculture, dramatically reducing the extant of wetlands in Hawai‘i (Van Rees & Reed, 2014). Together with the introduction of gun-based waterfowl hunting, and the introduction of nonnative predators, Hawaiian waterbirds declined to very small numbers and were listed as endangered in 1973 (Reed et al., 2011). Following listing, many populations are increasing, with a heavy reliance on vegetation management, water management, and predator control (J. G. Underwood et al., 2013).

A review of hatching and fledging success in the Hawaiian Stilt over the last 50 years suggests that these conservation efforts have been effective for increasing nesting success, but less successful at increasing fledging success (Idle et al., in prep). No comparable study of Hawaiian Coots or Hawaiian Gallinules has been done to date. Known causes of nest failure in Hawaiian waterbirds include flooding, predation, and abandonment (Harmon et al., 2021), with the majority of nest predation events attributed to mammals, based on studies of Hawaiian Stilts (Christensen et al., 2021, Katayama et al., in prep; Botet Rodriguez et al., in prep). In contrast, known causes of chick mortality include starvation, exposure, and predation, with the majority of mortalities in Hawaiian Stilts occurring within the first week after hatching (Ackerman et al., 2014, Idle et al., in prep). Similar to Hawaiian Stilts, survival in Hawaiian Gallinules chicks is lowest when they are most vulnerable, in the first 20 days after hatching (Webber 2024).

While predation is a risk at both the egg and chick stages, more species are known to predate chicks than eggs. Further, some waterbirds utilize the nest for several days after

hatching, but others leave as soon as the final egg has hatched, resulting in different risks of discovery by predators. Hawaiian Stilt chicks leave the nest within 24-48 hours after hatching (Christensen et al., 2021), and Hawaiian Gallinule chicks often remain in the nest for 1-3 days after hatching (Trnka, 2015) or perhaps even longer (Webber 2024). Thus, the habitat characteristics that protect eggs from predators may not reduce chick predation, and the relationship between nest-site characteristics and predation risk for chicks may differ among waterbird species.

Waterbirds in the Hawaiian Islands evolved in the absence of entire classes of predators, including mammals, amphibians, and reptiles (Pejchar et al., 2020). Prior to European arrival in 1778 to the Hawaiian Islands, only the Polynesian rat and Polynesian pig had been introduced to the islands (Shiels et al., 2014; Wehr et al., 2018). Since the 1800's a number of additional predators were introduced (Hays & Conant, 2007; Rodda & Savidge, 2007), and today, a variety of invasive mammals, birds, amphibians, reptiles, and invertebrates, alongside native birds, are all known to depredate waterbird eggs, chicks, and adults (K. Doyle, pers. comm., T. Bogardus, pers. comm., Christensen et al., 2021; Drigot, 2001; Harmon et al., 2021; Reed et al., 2012; Underwood et al., 2014; USFWS, 2011; Webber, 2024; USFWS, 2011). Prior to this study, published observations of predation by native birds included the predation of a Hawaiian Gallinule chick by ʻAukuʻu (Black-crowned Night Heron, *Nycticorax nycticorax hoactli*) (Webber, Thesis Manuscript 2024), and the predation of a Hawaiian Stilt chick by Pueo (Hawaiian Short- eared Owl, *Asio flammeus sandwichensis*) (Garcia-Heras et al., 2024).

To better understand the relationship between nest-site selection, predation risk, and chick survival in three precocial waterbird species, in this study I: (1) evaluated the relationship between breeding habitat characteristics and chick survival; and (2) determined the relationship between breeding habitat characteristics, predator detections at the nest, and fledging success. These three species co-occur on two islands, Oʻahu and Kauaʻi, but only a few wetlands on each of these islands support robust populations of all three species. Thus, this study was conducted at the largest wetland complex on Oʻahu, Kawainui- Hāmākua wetland complex, Hawaiʻi (Figure 1, 21.43272°N, -157.75211°W), which provides core habitat for all three species (U.S. Fish and Wildlife Service, 2011).

METHODS:

Study Sites

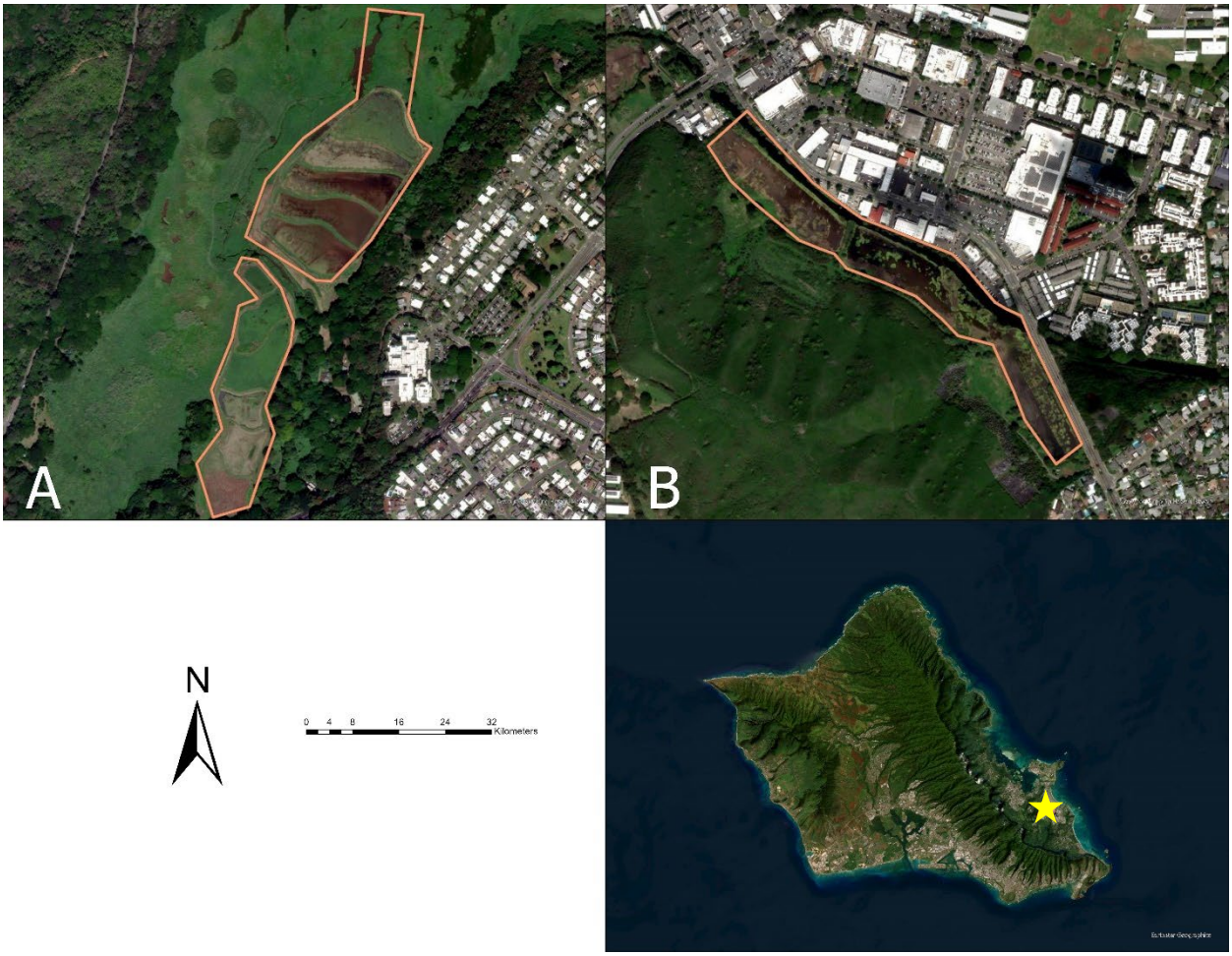


Figure1. Map of Kawainui (A) and Hāmākua Marsh (B) State Wildlife Sanctuary on the island of Oʻahu, Hawaiʻi.

Kawainui is comprised of eleven interior terraced cells (0.6 – 4.1 acres each). The pond system is bisected by Maunawili stream, dividing the North Ponds into 5 interior cells and the South Ponds into 6 interior cells. Each interior cell was constructed in an irregular mosaic pattern and water is supplied through rainfall and periodic flooding of Maunawili Stream Vegetation management of invasive species takes place from September-March, with the main goal of eliminating growth of invasive Californian Grass (*Urochloa mutica*) and promoting growth of wetland plants.

Hāmākua Marsh is a wetland with approximately 23 acres and is comprised of a complex of basins. The complex is divided by four different basins (A: 4.6 acres; B: 9.5 acres; C: 6 acres; D: 3.2 acres), and each basin is comprised of open water, vegetation and mudflat. Vegetation management of invasive species such as pickleweed (*Batis maritima*), takes place from September-March to increase mudflats for stilt nesting. Both wetlands have active vegetation management to promote nesting habitat for Hawaiian waterbirds (Price & Harmon, 2019).

Data Collection

Vegetation Measurements. The vegetation density was measured by visually estimating the percent of visual obstruction in the pole (VOR) by vegetation at four different segments (Journal & Jul, 1970). The vegetation height, vegetation cover and percentage of VOR, were measured at four different cardinal directions at random points two meters distance from the nest. We then averaged the vegetation density and height values among the four cardinal directions for subsequent analyses (Chiavacci et al., 2018; Journal & Jul, 1970)

Activities for the Hawaiian Stilt were conducted under permits held by the Price laboratory (Bird Banding Lab permit no. 24339 and 24137; United Fish & Wildlife Service Recovery Permit no. TE-25955C-3; Hawai‘i Department of Forestry and Wildlife Protected Wildlife Scientific Collecting no WL23-04 and WL20-05; University of Hawai‘i Institutional Animal Care and Use Committee protocol no. 172733-5).

Chick Surveys

For the 2022 and 2023 breeding seasons, weekly surveys were conducted from January through July in the Kawainui and Hāmākua Marshes to locate chicks of Hawaiian Stilts, Hawaiian Gallinules and Hawaiian Coots. Based on motion-activated camera detections from the nesting stage, we visited nests that were known to have hatched at least one chick. We also used behavioral cues such as adult defensive behaviors including alarm calling, dive bombing and/or wing-flapping, which are often associated with the defense of chicks. At each nest, a chick was hand captured by searching the vegetation surrounding nest sites, and chicks were marked on the head with nail polish to facilitate individual identification, as individuals were not able to be banded immediately after hatching due to the continued growth of the diameter of the legs during this growth stage. For each brood, chicks were weighed prior to attaching a transmitter to ensure

that the attachments were no more than 3% of each individual's body weight**.** Only one chick per brood was tagged.

Radio Transmitter Attachment

We glued a VHF radio transmitter (Holohil BD-2 (0.62g or 1.4g), LB-2X (0.41g) and for gallinules and coots (LB-2X ,0.41g). to the the back of each chick using the Livestock Identification Tag Cement glue brand, and by applying alcohol to the exposed skin and feathers in a small area about 1-2 cm above the uropygial gland (Jessica Idle., in prep Smetzer et al., 2001; Warnock & Warnock, 1993). Stilt individuals were radiotagged when they were at least seven days old (Reed et al 1998.); coot and gallinule chicks were radiotagged at a minimum of seven days old by DOFAW personnel.

Each chick was banded upon reaching an appropriate size and fitted with four bands - one Darvic plastic color band and one U.S. Geological Survey (USGS) Bird Banding Lab (BBL) numerical identification aluminum band (Size 6) on one leg and two Darvic plastic color bands on the other leg. Stilts were banded as soon as the tibiotarsal joint was large enough to prevent slipping of the band (generally at least ~10 days after hatching for stilts and six weeks after hatching for gallinules and coots). Chicks were held for no more than 30 minutes and released near their nest or the location they were captured after processing.

After the release, chicks were relocated using VHF receivers and/or through band re-sighting 1-2 times a day for 20-25 days after capture, until the radio was no longer attached, the battery died or until the individual fledged to ensure that transmitters were not negatively affecting the chicks (Colwell et al., 2007; Dinsmore et al., 2017).

The chick location was collected twice a day, separating observations by at least one hour to avoid autocorrelation of locations (Bogner & Baldassarre, 2002; White & Garrott,1990). If transmitters were observed to be loose, or had fallen off, transmitters were re-secured or reattached. Resighting of marked chicks without transmitters was recorded opportunistically when seen with a radio-tagged sibling and/or alone. In addition to the location of each chick, we obtained the following data: species, auxiliary marker, date, time, visual confirmation of the chick condition, bands (if present) and habitat type (i.e. vegetation, mudflat, water, mixed). Each location was recorded in ArcGIS Survey123 (ESRI, 2021).

Chick Fate

Chicks were classified as "deceased" if they were found dead, or if they disappeared (unknown fate) from the area suddenly and/or the radio transmitter fell off or was pulled off and the individual was not seen on subsequent surveys. We also classified the chick as deceased if we could no longer detect a VHF signal and the parents in the area were no longer giving behavioral indicators of defending a chick (Dinsmore et al., 2017). Individuals were classified as "fledged" if they were observed until their fledging period and all individuals who fledged were considered to have survived (Table 3 & 4). Causes of mortality were recorded by visual examination of a chick carcass, including bite marks on feathers or hard body parts, or predator tracks in nearby mud.

Chick Predator Detections

Camera photos were sorted and analyzed for predator detections using Mega Detector and Timelapse software. Mega Detector (Vélez et al., 2023) was used to detect photos of interest such as those with animals, people, and vehicles. Mega Detector is a free machine-learning model created by Microsoft AI for object detection that helps streamline image processing by eliminating false triggers (Fennell et al., 2022). Image results as potential detections by Mega Detector were incorporated into Timelapse (Greenberg et al., 2019) for image processing. We validated the data set by reviewing a subset of images (n=1,163,613) that were recognized and ranked by MegaDetector between a confidence of interval of 0.50-1.00. All other images containing humans and the remaining image set between 0-0.50 confidence of interval were discarded after reviewing a subset of images (n=100,000) to validate the absence of animal detections in the photos (Guo et al., 1996). To determine predator activity near nests, photos were analyzed for predator detections from nest initiation or discovery until 7 days after hatching. Photos were coded as '0' or '1'; '0' was assigned when a predator was not observed, and '1' was assigned when a predator was detected. Upon detecting a predator, the predator type was identified when possible.

Chick Survival

To determine chick survival until fledging, in-field radio tracking observations and motion-activated game cameras were utilized. We included camera data for predator detections from the first day after hatching until 7 days post-hatch of all nests, as this time period was shown in previous studies to have the highest mortality (Jessica Idle., in prep). Only nests in which at least one chick hatched and was marked using nail polish and/or fitted with a radiotransmitter were used for the analysis. This excluded nests that were already abandoned when they were found, and nests that had unknown fate due to a camera malfunction. The number of chicks that were marked with nail polish, fitted with transmitters and/or fitted with bands and successfully fledged were recorded as the total number of individuals who fledged.

Data Analysis

All analyses were conducted in the program R 4.1.0 (R Core Development Team, 2021). Utilizing time of day of each photograph we created graphs of activity by time of day for each animal species detected. Next, we used a general linear model (GLM) to examine if nest site characteristics and predator detections at the nest were related to chick survival. First, we used a logistic binomial regression to examine: (1) the relationship between predator detections at nest with chick fate of each species as response variable; and (2) the relationship between vegetation parameters and chick fate. For all our models, predator species were grouped in three different taxonomic groups: (1) mammals (rats, cats, Indian Mongoose), (2) avian predators (Cattle Egret, Black-crowned Night Heron), (3) other waterbirds (ducks, stilts, gallinules, coots), due to the effect of small sample sizes and correlation among individual species included in the same taxonomic group (Figure A.10.1, Appendix B). The first model consisted of three explanatory variables, detections of: (1) mammals, (2) avian predators, and (3) other watebirds (Chiavacci et al., 2018). The second model consisted of two explanatory variables: (1) vegetation density, and (2) vegetation height.

We also used a logistic exposure model to predict daily chick survival probability for stilts and gallinules. We used logistic exposure that is equivalent to logistic regression, with a custom logit link function that accounted for exposure days (Shaffer, 2004). Exposure days for each chick were from the first date the chick was radiotagged to the date the chick failed or was

successful, or to the last date the chick was known to have survived. The dates were scaled to the day on which the first nest hatched during the nesting season (Brudney et al., 2013; Dinsmore et al., 2017). We selected the top-ranked model from each model. We used 85% and corroborated models for parameters present in the competitive models that overlapped zero (Arnold, 2010).

For each model, we created a set of candidate models *a priori* based on the chick-fate and predator detections. Models were ranked using Akaike's information criterion corrected for small sample sizes to determine the probability that each model would be the best among the model set (AICc; Burnham & Anderson, 2002; Korner-Nievergelt et al., 2015). The analysis included days during the nesting and chick stage since the date of nest discovery was monitored with cameras (Chiavacci et al., 2018). Only chicks that were radiotagged were used for analyses. We also compared for models containing the terms "site" and "year" to test for differences in chick survival between study sites and years.

Results

We monitored a total of 59 Hawaiian Stilts chicks, 75 Hawaiian Gallinules chicks, and five Hawaiian Coots chicks, for a total of 139 waterbird chicks across 50 broods at Hāmākua Marsh (n=81) and Kawainui (n=58) (Table 3). Of these, 20 Hawaiian Stilts chicks, 36 Hawaiian Gallinules chicks and three Hawaiian Coots were fitted with radio-transmitters (Table 4, Figure 2 and Figure 3) and another 37 Hawaiian Stilts chicks, 38 Hawaiian Gallinules chicks and two Hawaiian Coots chicks were marked only with nail polish to allow for temporary visual identification. The bands and transmitters did not appear to obstruct movement of the chicks, and we observed no complications in the chicks marked with nail polish. Of all chicks monitored, 35 (25%) successfully fledged, 29 (21%) died, and 75 (54)% had unknown fates. Chick fate was marked as "unknown" if the chick disappeared after they were marked, the radiotransmitter fell off or was pulled off by the adult, and/or the battery failed before the chick fledged. Among the chicks that were known to have died, we confirmed that 5 (17%) died due predation. Of these, three chicks were discovered inside three different female bullfrog stomachs (Appendix B, Image 6). Furtheremore, we confirmed one and suspected two chicks predated by mongoose. One gallinule chick was seen on camera being consumed by a mongoose (Appendix B, Image 1). Two stilt chick remains were found, but the predator type could not be determined, however

mongoose predation was suspected due to remains found on site (Appendix B, Image 7). For the other 24 chicks that were found dead, we were not able to conduct a necropsy and unable to determine the cause of death due to the high state of decomposition of individuals when they were found.

Table 7. Hawaiian Stilt, Hawaiian Gallinule and Hawaiian Coot summary of all chicks monitored at the two nesting sites on the island of Oʻahu, Hawaiʻi in the 2022 and 2023 nesting seasons. N/A indicates a value that was not applicable and/or could not be calculated.

Species	Site	# Broods	Chicks Hatched (n)	Chicks Confirmed Dead	Chicks Fledged	Unknown Fate
Stilts						
Year 2022	Hāmakuā	8	26	4 (15%)	15 (58%)	7 (27%)
	Kawainui	2	5	1 (20%)	4 (80%)	0 (0%)
Year 2023	Hāmakuā	7	18	6 (33%)	12 (67%)	0 (0%)
	Kawainui	5	10	1 (10%)	1 (10%)	8 (80%)
Gallinules						
Year 2022	Hāmakuā	3	5	1 (20%)	2 (40%)	2 (40%)
	Kawainui	4	18	7 (39%)	0 (0%)	11 (61%)
Year 2023	Hāmakuā	13	31	4 (13%)	1 (3%)	26 (84%)
	Kawainui	5	21	4 (19%)	0%	17 (81%)
Coots						
Year 2022	Hāmakuā	NA	NA	NA	NA	NA
	Kawainui	NA	NA	NA	NA	NA
Year 2023	Hāmakuā	1	1	0 (0%)	0 (0%)	1 (100%)
	Kawainui	2	4	1 (25%)	0 (0%)	3 (75%)
Total			**139**	**29 (21%)**	**35 (25%)**	**75 (54%)**

Table 8. Hawaiian Stilt, Hawaiian Gallinule & Hawaiian Coot summary of radiotagged chicks at the two nesting sites on the island of Oʻahu, Hawaiʻi in the 2022- 2023 nesting breeding seasons. N/A indicates a value that was not applicable and/or could not be calculated.

Species	Site	# Broods	Chicks (n)	Chicks Dead	Fledglings	Uknown Fate
Stilts						
Year 2022	Hāmakuā	7	9	2 (22%)	6 (67%)	1 (11%)
	Kawainui	0	0	0	0	0

Year 2023	Hāmakuā	6	7	2 (29%)	5 (71%)	0 (0%)
	Kawainui	4	4	1 (25%)	1 (25%)	2 (50%)
Gallinules						
Year 2022	Hāmakuā	3	4	2 (50%)	1 (25%)	1 (25%)
	Kawainui	4	7	7 (100%)	0 (0%)	0 (0%)
Year 2023	Hāmakuā	13	17	2 (12%)	1 (6%)	14 (82%)
	Kawainui	4	8	2 (25%)	0 (0%)	6 (75%)
Coots						
Year 2022	Hāmakuā	0	0	0	0	0
	Kawainui	0	0	0	0	0
Year 2023	Hāmakuā	1	1	0 (0%)	0 (0%)	1 (100%)
	Kawainui	2	2	1 (50%)	0 (0%)	1 (50%)
Total			**59**	**19 (32%)**	**14 (24%)**	**26 (44%)**

Figure 2. Stilt and gallinule chick daily movement location points (2022 and 2023) during the interval of the first seven days after radiotagging at Hāmākua Marsh State Wildlife Sanctuary on the island of O‘ahu, Hawai‘i. Coot chicks (n=3) were not included in the map due to a small sample size.

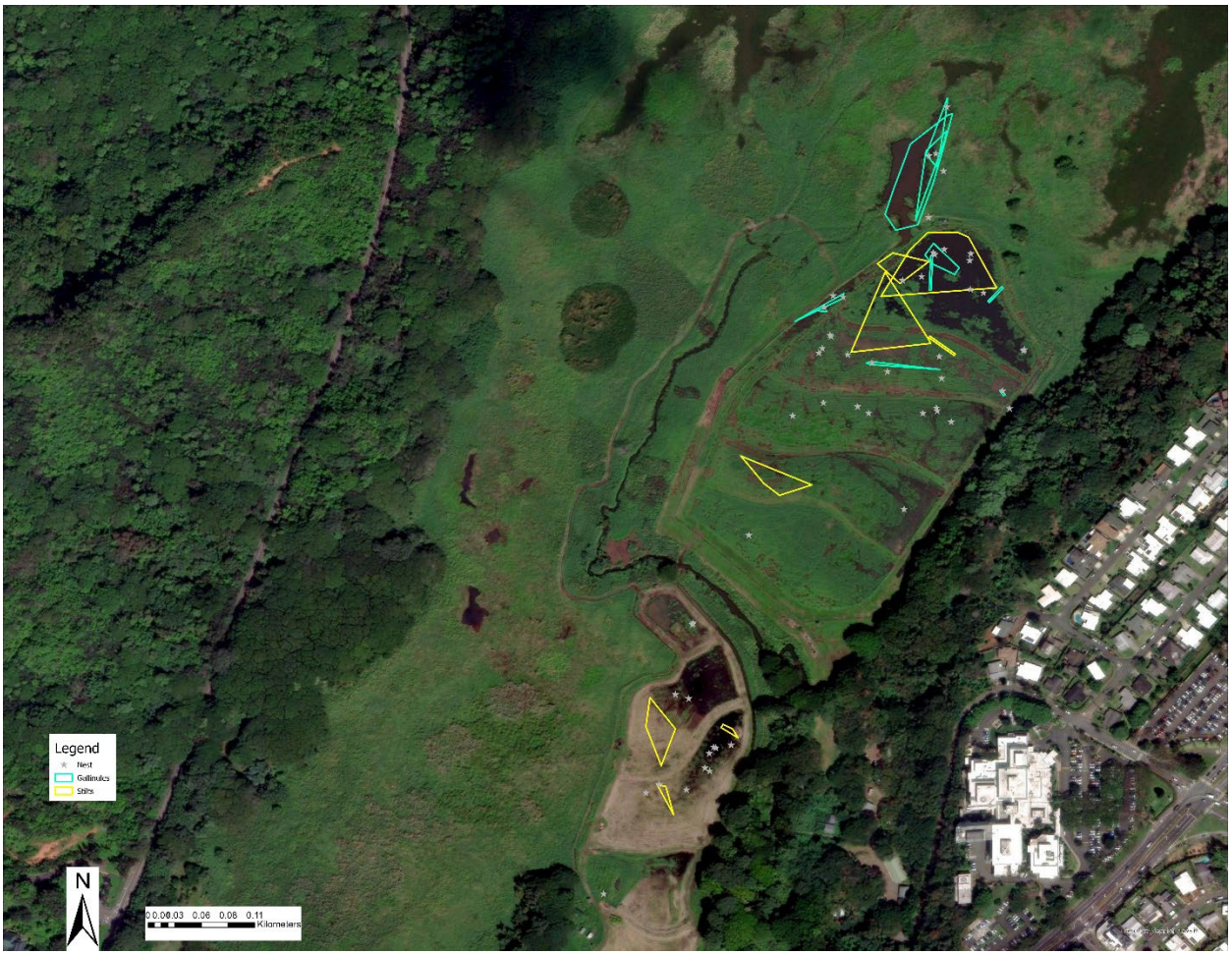


Figure 3. Stilt and gallinule chick daily movement relocation points (2022 and 2023) during the interval of the first seven days after radio tagging at Kawainui Marsh State Wildlife Sanctuary on the island of O‘ahu, Hawai‘i. Coot chicks (n=3) were not included in the map due to a small sample size.

Chick Survival: AICc Model Selection

The null model was the top model for both species, suggesting the predator detections at the nest were not strongly predictive of chick survival. In the stilt model set, the avian predator model was second best, with a 0.264 Akaike model weight. There was a negative relationship between mammal detections and the survival of stilt chicks (Table 10). In the gallinule model set, the ground birds model was second best, with a 0.188 Akaike model weight. There was a negative relationship between native bird detections and the probability that the gallinule chick survived until 7 days old.

Table 9. Model selection of predator detections of Hawaiian Stilts chicks (n=21) and Hawaiian Gallinule (n=25) during the nesting and chick stage in regards chick fate at Hāmakuā and Kawainui. Models were ranked using Akaike's Information Criterion corrected for small sample sizes (AICc) and reported as the change in AICc value from the best-performing model (ΔAICc). K is the number of model parameters in each model. *wi* is the Akaike model weight. *(Stilts: R2 = 1.0, SE = 0.5, P = 0.08; Gallinules: R2 = -3.09, SE = 1.0, P=0.003)*

Stilts	K	AICc	ΔAICc	*wi*	LL
Null*	1	24.1	0	0.337	-10.95
Avian Predators	2	24.6	0.49	0.264	-9.937
Other Waterbirds	2	25.1	0.94	0.21	-10.163
Mammals	2	26	1.88	0.131	-10.636
Mammals + Avian Predators + Other Waterbirds	4	27.7	3.53	0.058	-8.403

Gallinules	K	AICc	ΔAICc	*wi*	LL
Null*	1	10.4	0	0.46	-4.113
Other Waterbirds	2	12.2	1.79	0.188	-3.803
Avian Predators	2	12.3	1.91	0.177	-3.862
Mammals	2	12.5	2.12	0.159	-3.97
Mammals + Avian Predators + Other Waterbirds	4	17.3	6.86	0.015	-3.525

*****Coots chicks (n=3) were not included in the analysis due to a small sample size.

Figure 4. Logistic exposure model showing impact of day of the nesting season on stilt (n=21) chick survival probability at Kawainui and Hāmākua Marsh State Wildlife during 2022 and 2023 breeding seasons. Solid line represents daily survival probability estimated using parameters from the best fit model. Shaded area represents upper and lower 85% confidence intervals for the estimated daily survival probability.

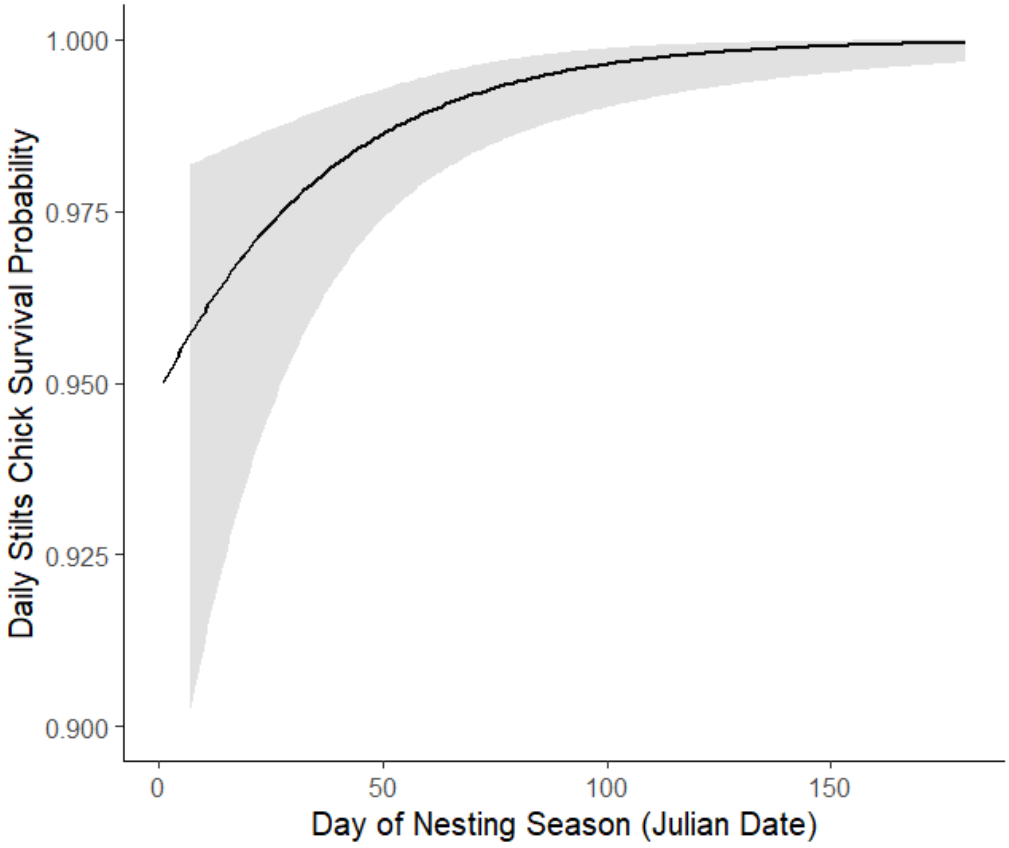


Figure 5. Logistic exposure model showing impact of day of the nesting season on gallinule (n=25) chick survival probability at Kawainui and Hāmākua Marsh State Wildlife during 2022 and 2023 breeding seasons. Solid line represents daily survival probability estimated using parameters from the best fit model. Shaded area represents upper and lower 85% confidence intervals for the estimated daily survival probability (*P-value*= 0.008 / *McFadden R-squared*= 0.12).

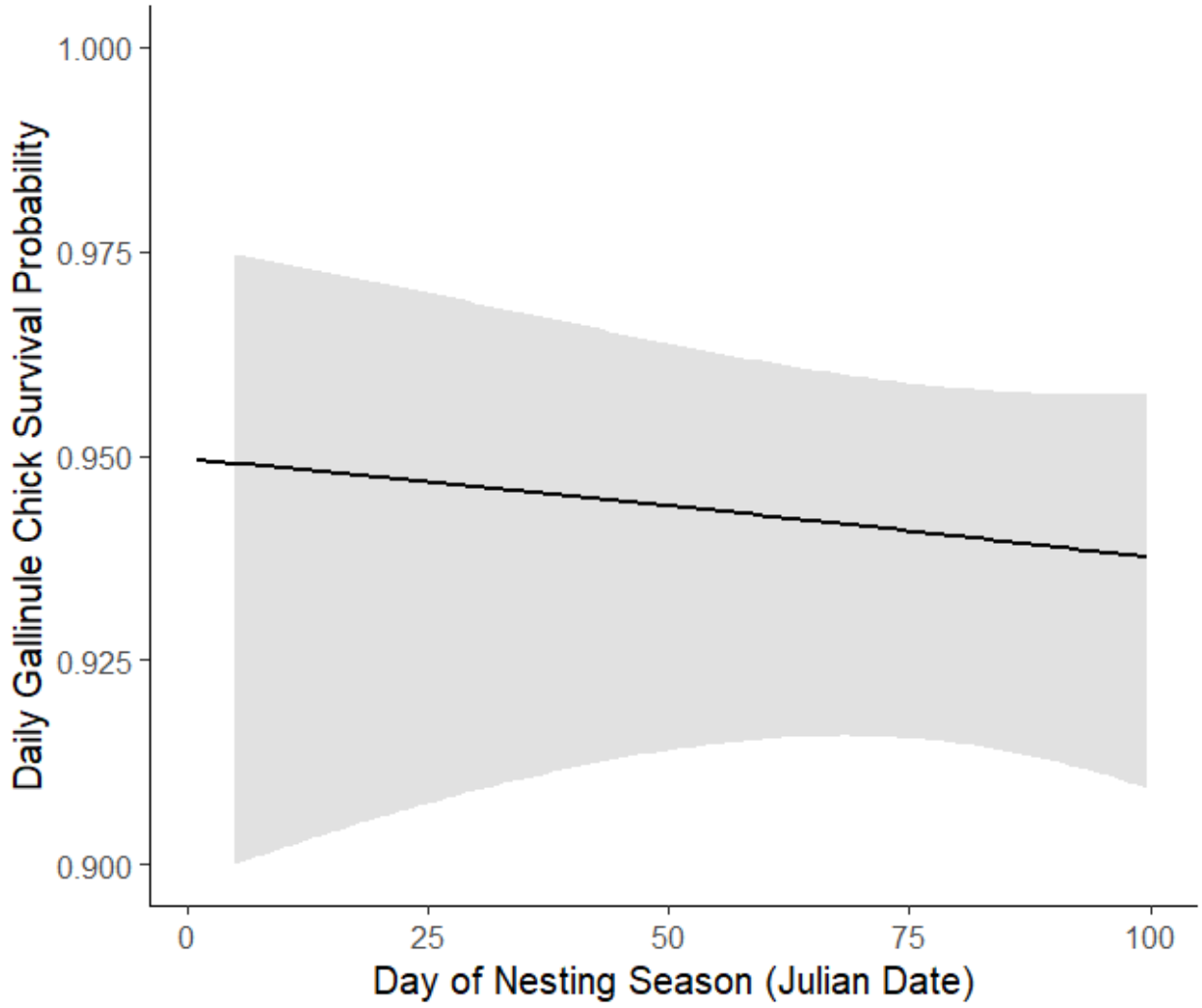


Figure 6. Logistic exposure model showing impact of chick age (days) on stilt (n=21) chick survival probability at Kawainui and Hāmākua Marsh State Wildlife during 2022 and 2023 breeding seasons. Solid line represents daily survival probability estimated using parameters from the best fit model. Shaded area represents upper and lower 85% confidence intervals for the estimated daily survival probability (*P-value*= 0.6 / *McFadden R-squared*= 0.001).

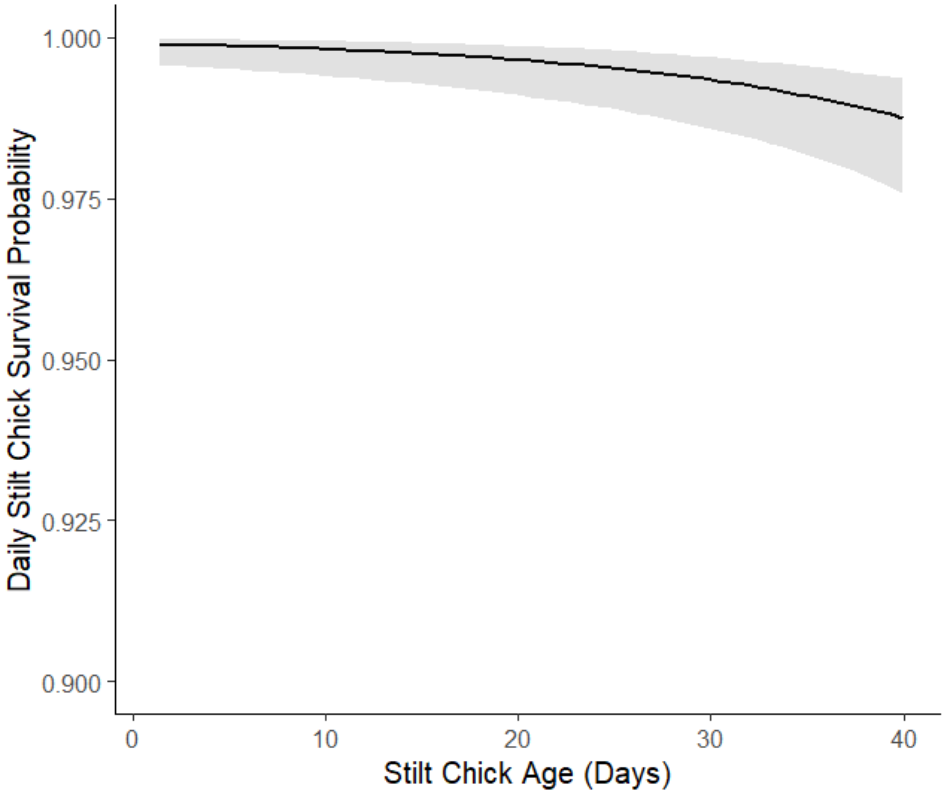
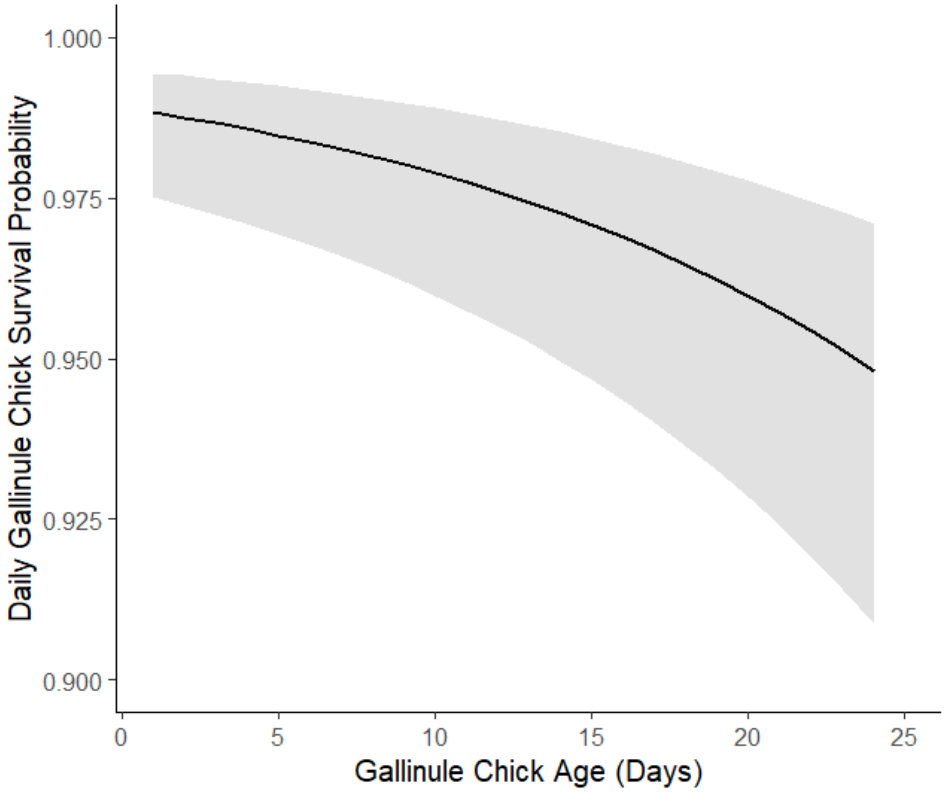


Figure 7. Logistic exposure model showing impact of chick age (days) season on gallinules (n=25) chick survival probability at Kawainui and Hāmākua Marsh State Wildlife during 2022 and 2023 breeding seasons. Solid line represents daily survival probability estimated using parameters from the best fit model. Shaded area represents upper and lower 85% confidence intervals for the estimated daily survival probability (*P-value*= 0.002 / *McFadden R-squared*= 0.15).



The gallinule daily chick survival model predicted a 3% decrease in gallinule chick survival after 15 days (*P-value*= 7.74e-06 / *McFadden R-squared*= 0.56)

Activity varied by time of day among potential predators and the waterbird species. Overall, egrets, mongooses, mynas, herons and turtles showed diurnal activity patterns and cats, bullfrogs and rats were most active during nocturnal hours (Figure A.6.1 and Figure A.7.1, Appendix A) The three focal species in this study were most active during the day, but ducks were active at all hours of the day and night (Figure A.5.1, Appendix A).

DISCUSSION

While invasive and native predators are well known as a major cause of nest failure in endangered Hawaiian waterbirds (Christensen et al. 2021, Harmon et al. 2021), prior to this study there had been no quantitative comparison of the relative impact of various potential predators on the chick stage of these three species. Further, as most waterbird conservation efforts have been focused on creating suitable nesting habitat and controlling mammalian predators, we wished to examine whether nest-site characteristics and predator detections at the nest were associated with chick survival in precocial species that leave the nest within a few days of hatching. We examined the differential predator impacts and nest-site characteristics on chick survival of Hawaiian Stilt (*Himantopus mexicanus knudseni*), Hawaiian Gallinule (*Gallinula galeata sandvicensis*) and Hawaiian Coot; *Fulica alai*). We found that both nest site characteristics and most predator types detected at the nest were not associated with chick survival, with the exception of mammals. Importantly, this implies that efforts to improve nesting success may not simultaneously improve fledging success. Targeted efforts are needed to improve chick survival, including a broader suite of predator control methods.

Predation is well-documented as the main cause of chick mortality in precocial species (Dinsmore et al., 2017; Dreitz, 2009; Schekkerman, Hans; Boele, 2008). Although sample sizes limited our ability to run individual models, across all three waterbird species combined we found that the probability of chick survival declined with increased detections of invasive mammals. Although there was no evidence of a transmitter found in the stomach of mammalian predators, we found direct evidence of predation of a gallinule chick by a mongoose and two suspected depredation events of stilt chicks by mongoose based on trace evidence. Thus, improved removal techniques for Small Indian Mongoose will improve conservation outcomes at both the nest and chick stages.

In additional to mammals, a wide variety of invasive birds, amphibians, reptiles, and invertebrates, alongside native birds, have been documented depredating waterbird chicks (K. Doyle, pers. comm., T. Bogardus, pers. comm., Christensen et al., 2021; Drigot, 2001; Harmon et al., 2021; Reed et al., 2012; Underwood et al., 2014; USFWS, 2011; Webber, 2024; USFWS, 2011), but few management tools exist to facilitate their removal. In this study, three gallinule chicks were found in the stomachs of bullfrogs and we found direct evidence of depredation by

Indian Mongoose (Image 1 and Image 7, Appendix B), but we were unable to determine the cause of death or disappearance for the majority of the chicks tracked, similar to other studies (Idle et al., in prep). Thus, it is likely that some of other predators known to depredate waterbirds were responsible for at least some of these deaths, but our tracking methods were ineffective at identifying these predators. While mongoose-labeled bait has been in development by USDA-Aphis (pers. comm.), to date no effective control for American Bullfrogs has been identified (Hossack et al., 2023; J. , G. Underwood & Letchworth, 2016), other herpetofauna such as invasive Red-eared Sliders are also known to depredate waterbird chicks (T. Bogardus, pers.comm.), and similarly have no effective removal techniques other than hand removal. Invasive invertebrates that depredate chicks, such as Mud Crabs, are harvested as a human food resource and perhaps may be managed to minimize impacts during the nesting season.

Given that many of the non-mammalian predators of waterbirds are dependent upon water to some degree, this may offer some insights into potential management approaches. American Bullfrogs are dependent upon freshwater resources for their life cycle and were thus absent from one of our study sites where the water is brackish. Thus, in locations where it is feasible, promotion of brackish conditions may reduce bullfrog populations. Manipulation of water levels has also been used effectively to reduce the abundance of avian predators in nesting areas (K. Goodale, pers. comm.). Previous studies suggest that water levels may alter predation risk, improving overall the nesting survival (Schmidt et al., 2023) as water levels have been shown to be an important factor for foraging decisions by predators (Maccarone et al., 2015). Water levels may also be important to food production for chicks. As some chicks in previous studies appeared emaciated, suggesting they died from a lack of food (Idle et al., in prep), this is an important direction for further inquiry.

As a previous study of Hawaiian Stilts suggested that earlier nests are more successful than later nests (Harmon et al. 2021), we expected the same would be true for chicks. Water levels fluctuations and predator abundance across the nesting season may influence seasonality in chick survival, as well as food availability for chicks (Bellebaum & Bock, 2009; Eglington et al., 2008). However, we found that chicks that hatched later in the season had higher survival than stilts that hatched earlier in the season, in contrast with gallinule chicks, which had lower survival later in the season than chicks that hatched earlier. While no previous studies have

examined seasonality in chick survival in these two taxa for comparison, studies of other precocial species suggest that chicks that hatch later in the season have higher survival rates (Colwell et al., 2007; Dinsmore et al., 2017). Predator abundances may differ throughout the season, as well as food resources or cover (Clark et al., 2003). Given the lack of studies on seasonal influences on chick survival in Hawaiian waterbirds, particularly compared with the abundance of studies of nest survival, this is an important area for further inquiry.

To our knowledge, this is the first study to examine the temporal niches of the predator-prey community that these waterbirds inhabit. Mammals such as cats and rats are likely to pose the highest risk at night for waterbirds and their chicks, particularly given their ability to detect chicks using olfactory and auditory cues. During the day when chicks are actively searching for food, the remaining predators are likely to pose the highest risk. Temporal activity patterns may also provide insights for managers looking to optimize trapping or other removal techniques by targeting times of day when predators are the most active.

Our study is the first to examine whether nest-site characteristics and predators detected at the nest are related to chick survival in three Hawaiian waterbirds. While nesting success has improved over the last 50 years due to focused management efforts (Idle et al., in prep), improvements to fledging success have lagged behind. Our study suggests this is because the actions that benefit the nesting stage differ from those needed to improve outcomes for chicks. Improved management techniques for a broad suite of invasive predators, particularly amphibians, reptiles, and invertebrates, is crucial to improve chick survival in these three endangered waterbird species.

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Appendix A

Table A.1. Summary of all nests found and monitored during the study period. Light blue highlighted rows indicate nests that were predated.

NestID	Species	Site	Clutch Size	Chicks Hatched	Nest Fate[1]	Predator
HS01-2022	Stilt	Hāmakuā	4	4	Successful	
HS02-2022	Stilt	Hāmakuā	1	0	Failed: Unknown	
HS03-2022	Stilt	Hāmakuā	1	0	Failed: Unknown	
HS04-2022	Stilt	Hāmakuā	4	4	Successful	
HS05-2022	Stilt	Hāmakuā	4	4	Successful	
HS06-2022	Stilt	Hāmakuā	4	2	Successful	
HS07-2022	Stilt	Hāmakuā	4	2	Successful	
HS08-2022	Stilt	Hāmakuā	4	4	Successful	
HS09-2022	Stilt	Hāmakuā	4	4	Successful	
HS10-2022	Stilt	Hāmakuā	1	0	Failed: Unknown	
HS11-2022	Stilt	Hāmakuā	4	0	Failed: Abandoned	
HS12-2022	Stilt	Hāmakuā	4	4	Successful	
HS13-2022	Stilt	Hāmakuā	4	0	Failed: Predation	Unknown
HS14-2022	Stilt	Hāmakuā	1	0	Failed: Predation	Unknown
HS15-2022	Stilt	Hāmakuā	1	0	Failed: Predation	Unknown
KS01-2022	Stilt	Kawainui	4	2	Successful	
KS02-2022	Stilt	Kawainui	4	4	Successful	
HG01-2022	Gallinule	Hāmakuā	2	0	Failed: Predation	Unknown
HG02-2022	Gallinule	Hāmakuā	6	0	Failed: Abandoned	
HG03-2022	Gallinule	Hāmakuā	4	4	Successful	
HG04-2022	Gallinule	Hāmakuā	4	2	Successful	
HG05-2022	Gallinule	Hāmakuā	5	0	Failed: Abandoned	
HG06-2022	Gallinule	Hāmakuā	5	5	Successful	
KG01-2022	Gallinule	Kawainui	4	0	Failed: Predation	Unknown
KG02-2022	Gallinule	Kawainui	3	0	Failed: Unknown	
KG04-2022	Gallinule	Kawainui	6	0	Failed: Unknown	
KG05-2022	Gallinule	Kawainui	7	7	Successful	

KG06-2022	Gallinule	Kawainui	5	0	Failed: Unknown	
KG07-2022	Gallinule	Kawainui	4	0	Failed: Unknown	
KG08-2022	Gallinule	Kawainui	5	0	Failed: Predation	Gallinule
KG09-2022	Gallinule	Kawainui	6	0	Failed: Predation	Mongoose
KG10-2022	Gallinule	Kawainui	4	3	Successful	
KG11-2022	Gallinule	Kawainui	7	3	Successful	
KG12-2022	Gallinule	Kawainui	4	3	Successful	
HC01-2022	Coot	Hāmakuā	Unknown[2]	3	Successful	
HC02-2022	Coot	Hāmakuā	4	0	Failed: Unknown	
KC01-2022	Coot	Kawainui	6	2	Successful	
KC02-2022	Coot	Kawainui	4	0	Failed: Flooded	
KC03-2022	Coot	Kawainui	4	1	Successful	
KS01-2023	Stilt	Kawainui	4	2	Successful: Partial Predation	Gallinule
KS02-2023	Stilt	Kawainui	4	4	Successful	
KS03-2023	Stilt	Kawainui	3	1	Successful	
KS04-2023	Stilt	Kawainui	4	0	Failed: Abandoned	
KS05-2023	Stilt	Kawainui	4	4	Successful	
KS06-2023	Stilt	Kawainui	3	3	Successful	
KS07-2023	Stilt	Kawainui	4	3	Successful	
KS08-2023	Stilt	Kawainui	3	0	Failed: Abandoned	
KS09-2023	Stilt	Kawainui	2	0	Failed: Abandoned	
KS10-2023	Stilt	Kawainui	4	1	Successful	
KS11-2023	Stilt	Kawainui	4	0	Failed: Predation	Mongoose
HS01-2023	Stilt	Hāmakuā	4	3	Failed: Unknown	
HS02-2023	Stilt	Hāmakuā	4	4	Successful	
HS03-2023	Stilt	Hāmakuā	4	4	Successful	
HS04-2023	Stilt	Hāmakuā	4	0	Successful	
HS05-2023	Stilt	Hāmakuā	4	0	Failed: Predation	Mongoose
HS06-2023	Stilt	Hāmakuā	4	0	Failed: Predation	Mongoose
HS07-2023	Stilt	Hāmakuā	4	3	Failed: Flooded/ Partial Predation	Coot
HS08-2023	Stilt	Hāmakuā	4	3	Successful	

HS09-2023	Stilt	Hāmakuā	4	0	Successful	
HS10-2023	Stilt	Hāmakuā	4	3	Failed: Predation	Mongoose
HS11-2023	Stilt	Hāmakuā	3	0	Successful	
HS12-2023	Stilt	Hāmakuā	4	0	Failed: Abandoned	
HS13-2023	Stilt	Hāmakuā	4	0	Failed: Predation	Mongoose
HS14-2023	Stilt	Hāmakuā	3	0	Failed: Predation	Mongoose
HS15-2023	Stilt	Hāmakuā	4	0	Failed: Abandoned	
HS16-2023	Stilt	Hāmakuā	4	0	Failed: Predation	Mongoose
HS17-2023	Stilt	Hāmakuā	4	0	Failed: Predation	Mongoose
HS18-2023	Stilt	Hāmakuā	4	0	Failed: Predation	Mongoose
HS19-2023	Stilt	Hāmakuā	4	0	Failed: Predation	Mongoose
HS20-2023	Stilt	Hāmakuā	1	0	Failed: Abandoned	
HS21-2023	Stilt	Hāmakuā	4	3	Successful	
HG01-2023	Gallinule	Hāmakuā	5	0	Failed: Predation	Mongoose
HG02-2023	Gallinule	Hāmakuā	9	4	Successful	
HG03-2023	Gallinule	Hāmakuā	5	0	Failed: Self depredation	Self-depredation
KG01-2023	Gallinule	Kawainui	5	5	Successful	
KG02-2023	Gallinule	Kawainui	3	0	Failed: Self depredation	Self-depredation
KG03-2023	Gallinule	Kawainui	6	6	Successful	
KG04-2023	Gallinule	Kawainui	5	5	Successful	
KG05-2023	Gallinule	Kawainui	5	4	Successful	
UG01-2023	Gallinule	Ulupō	4	4	Successful	
HG04-2023	Gallinule	Hāmakuā	3	0	Failed: Flooded	
KG06-2023	Gallinule	Kawainui	5	0	Failed: Flooded	
HG05-2023	Gallinule	Hāmakuā	4	1	Successful	
HG06-2023	Gallinule	Hāmakuā	1	0	Failed: Flooded	
HG07-2023	Gallinule	Hāmakuā	4	4	Successful	
HG08-2023	Gallinule	Hāmakuā	5	3	Successful	
HG09-2023	Gallinule	Hāmakuā	4	0	Failed: Abandoned	
KG07-2023	Gallinule	Kawainui	4	0	Failed: Predation	Gallinule

KG08-2023	Gallinule	Kawainui	1	0	Failed: Abandoned	
KG09-2023	Gallinule	Kawainui	6	0	Failed: Flooded	
HG10-2023	Gallinule	Hāmakuā	5	0	Failed: Abandoned	
HG11-2023	Gallinule	Hāmakuā	5	3	Successful	
HG12-2023	Gallinule	Hāmakuā	6	6	Successful	
HG13-2023	Gallinule	Hāmakuā	7	5	Successful	
HG14-2023	Gallinule	Hāmakuā	5	0	Failed: Abandoned	
KG10-2023	Gallinule	Hāmakuā	6	0	Failed: Flooded	
HG15-2023	Gallinule	Hāmakuā	2	0	Failed: Predation	
HG16-2023	Gallinule	Hāmakuā	4	0	Failed: Flooded	
HG17-2023	Gallinule	Hāmakuā	6	4	Successful	
HG18-2023	Gallinule	Hāmakuā	6	5	Successful	
HG19-2023	Gallinule	Hāmakuā	6	3	Successful	
HG20-2023	Gallinule	Hāmakuā	6	0	Failed: Flooded	
HG21-2023	Gallinule	Hāmakuā	5	0	Failed: Flooded	
HG22-2023	Gallinule	Hāmakuā	7	0	Failed: Flooded	
KG11-2023	Gallinule	Kawainui	5	0	Failed: Flooded	
KG12-2023	Gallinule	Kawainui	5	0	Failed: Flooded	
HG23-2023	Gallinule	Hāmakuā	4	0	Failed: Flooded	
KG13-2023	Gallinule	Kawainui	6	2	Successful: Partial Predation	Mongoose
KG14-2023	Gallinule	Kawainui	6	4	Successful	
UG02-2023	Gallinule	Ulupō	8	3	Successful	
HG24-2023	Gallinule	Hāmakuā	4	4	Successful	
HG25-2023	Gallinule	Hāmakuā	4	0	Failed: Abandoned	
HG26-2023	Gallinule	Hāmakuā	6	6	Successful	
HG27-2023	Gallinule	Hāmakuā	6	0	Failed: Predation	Mongoose
HG28-2023	Gallinule	Hāmakuā	5	4	Successful	
HG29-2023	Gallinule	Hāmakuā	6	4	Successful	
HG30-2023	Gallinule	Hāmakuā	3	3	Successful	
HG31-2023	Gallinule	Hāmakuā	4	1	Successful	
HG32-2023	Gallinule	Hāmakuā	4	0	Failed: Self depredation	Self-depredation

KC01-2023	Coot	Kawainui	5	4	Successful	
KC02-2023	Coot	Kawainui	6	4	Successful	
KC03-2023	Coot	Kawainui	3	2	Successful	
KC04-2023	Coot	Kawainui	4	2	Successful	
KC05-2023	Coot	Kawainui	4	3	Successful	
HC01-2023	Coot	Hāmakuā	4	0	Failed: Abandoned	
HC02-2023	Coot	Hāmakuā	5	0	Failed: Abandoned	
HC03-2023	Coot	Hāmakuā	1	0	Failed: Abandoned	
HC04-2023	Coot	Hāmakuā	4	0	Failed: Abandoned	
HC05-2023	Coot	Hāmakuā	4	4	Successful	
KC06-2023	Coot	Kawainui	5	5	Successful	
KC07-2023	Coot	Kawainui	4	0	Failed: Abandoned	
HC06-2023	Coot	Hāmakuā	3	0	Failed: Unknown	
HC07-2023	Coot	Hāmakuā	Unknown[2]	2	Successful	
HC08-2023	Coot	Hāmakuā	4	0	Faile: Predation	Mongoose

[1]Nest fates were classified as successful if at least one egg hatched and failed if the eggs disappeared or were abandoned before the expected hatch date. Nest were classified as "fail predation" if there were signs of predation, e.g. eggshells with holes characteristic of predation left in nest, a predator was captured on camera or predator/scats present at or near the nest. And nests were classified as "fail unknown" if there were no signs or evidence of a predation event.

[2]Nest was found after the eggs hatched, clutch size is unknown.

Table A.2. Summary of all monitored chicks at Kawainui and Hāmakuā Marsh State Wildlife Sanctuaries during the study period. Light blue highlighted rows indicate radio-tagged chicks.

Nest ID	Species	Site	Band ID/ Color Marker	Radio tagged?	Radio-Tracking Duration (days)	#Sightings	Radio-tag fate	Dead	Chick Fate[1]
HS01-2022	Stilt	Hāmakuā	OA:YK/ff	Y	26	30	Fell/pecked off	N	Fledged
HS01-2022	Stilt	Hāmakuā	Mauve	N	NA	NA	Carcass found	Y	Unknown mortality
HS01-2022	Stilt	Hāmakuā	Yellow	N	NA	2	NA	NA	Uknown fate
HS04-2022	Stilt	Hāmakuā	White	N	NA	8	NA	NA	Uknown fate

HS04-2022	Stilt	Hāmakuā	Yellow	N	NA	8	NA	NA	Uknown fate
HS04-2022	Stilt	Hāmakuā	Turqousie	N	NA	8	NA	NA	Uknown fate
HS04-2022	Stilt	Hāmakuā	Red	Y	5	12	NA	Y	Predated
HS04-2022	Stilt	Hāmakuā	OA:SB/ff	Y	18	22	Battery Failure	NA	Uknown fate
HS05-2022	Stilt	Hāmakuā	Yellow	N	NA	1	NA	Y	Unknown mortality
HS05-2022	Stilt	Hāmakuā	Fuschia	N	NA	1	NA	NA	Uknown fate
HS05-2022	Stilt	Hāmakuā	OA:RY/ff	Y	26	27	Battery Failure	N	Fledged
HS06-2022	Stilt	Hāmakuā	OK/ff:OA	Y	2	2	Radio tag on ground	Y	Unknown Predated
HS06-2022	Stilt	Hāmakuā	OA:KK/ff	Y	17	20	Battery Failure	N	Fledged
HS07-2022	Stilt	Hāmakuā	Hot pink	N	NA	4	NA	NA	Uknown fate
HS08-2022	Stilt	Hāmakuā	OA:BK/ff	Y	2	9	Battery Failure	N	Fledged
HS08-2022	Stilt	Hāmakuā	OA:RS/ff	N	NA	11	NA	N	Fledged
HS08-2022	Stilt	Hāmakuā	WW/ff:OA	N	NA	15	NA	N	Fledged
HS08-2022	Stilt	Hāmakuā	KW/ff:OA	N	NA	7	NA	N	Fledged
HS09-2022	Stilt	Hāmakuā	OA:YS/ff	Y	25	27	Battery Failure	N	Fledged
HS09-2022	Stilt	Hāmakuā	OA:YB/ff	N	NA	11	NA	N	Fledged
HS09-2022	Stilt	Hāmakuā	OA:SK/ff	N	NA	10	NA	N	Fledged
HS09-2022	Stilt	Hāmakuā	OA:OK/ff	N	NA	9	NA	N	Fledged
HS12-2022	Stilt	Hāmakuā	OA:SW/ff	N	NA	15	NA	N	Fledged
HS12-2022	Stilt	Hāmakuā	OA:RL/ff	N	NA	16	NA	N	Fledged
HS12-2022	Stilt	Hāmakuā	LO/ff:AO	N	NA	9	NA	N	Fledged
HS12-2022	Stilt	Hāmakuā	OA:OB/ff	Y	24	29	Fell off	N	Fledged
HG03-2022	Gallinule	Hāmakuā	Yellow	Y	7	5	Uknown	Y	Uknown predation
HG04-2022	Gallinule	Hāmakuā	Red	Y	5	5	Fell off	NA	Unknown fate
HG04-2022	Gallinule	Hāmakuā	White	Y	11	23	Battery Failure	N	Fledged
HG06-2022	Gallinule	Hāmakuā	White	Y	21	27	Battery Failure	N	Fledged
HG06-2022	Gallinule	Hāmakuā	Orange	N	NA	1	NA	NA	Unknown Fate
UG02-2022	Gallinule	Ulupō	Blue	Y	1	6	Fell/pecked off	N	Unknown mortality
UG02-2022	Gallinule	Ulupō	Pink	Y	7	7	Bullfrog	Y	Predated: Bullfrog

UG02-2022	Gallinule	Ulupō	Yellow	Y	25	22	Fell/pecked off	Y	Unknown mortality
KG05-2022	Gallinule	Kawainui	Red	N	NA	1	NA	NA	Unknown Fate
KG05-2022	Gallinule	Kawainui	Shamrock	N	NA	2	NA	NA	Unknown Fate
KG05-2022	Gallinule	Kawainui	Mauve	N	NA	2	NA	NA	Unknown Fate
KG05-2022	Gallinule	Kawainui	Yellow	Y	5	3	Bullfrog	Y	Predated: Bullfrog
KG05-2022	Gallinule	Kawainui	White	N	NA	1	NA	NA	Unknown Fate
KG05-2022	Gallinule	Kawainui	Turquoise	N	NA	2	NA	NA	Unknown Fate
KG05-2022	Gallinule	Kawainui	Orange	N	NA	1	NA	NA	Unknown Fate
KG10-2022	Gallinule	Kawainui	Yellow	Y	5	7	Bullfrog	Y	Predated: Bullfrog
KG10-2022	Gallinule	Kawainui	Blue	N	NA	3	NA	NA	Unknown Fate
KG11-2022	Gallinule	Kawainui	Yellow	Y	4	4	Fell/pecked off	Y	Unknown mortality
KG11-2022	Gallinule	Kawainui	Red	N	NA	1	NA	NA	Unknown Fate
KG11-2022	Gallinule	Kawainui	Blue	N	NA	1	NA	NA	Unknown Fate
KG12-2022	Gallinule	Kawainui	Yellow	Y	14	16	Uknown	Y	Unknown predation
KG12-2022	Gallinule	Kawainui	Blue	N	NA	9	NA	NA	Unknown Fate
KG12-2022	Gallinule	Kawainui	Light Blue	N	NA	7	NA	NA	Unknown Fate
KS01-2022	Stilt	Kawainui	YL/ff:AO	N	2	NA	NA	N	Fledged
KS01-2022	Stilt	Kawainui	BY/ff:OA	N	NA	9	NA	N	Fledged
KS01-2022	Stilt	Kawainui	WR/ff:OA	N	3	3	NA	Y	Unknown mortality
KS01-2022	Stilt	Kawainui	OA:GG/ff	Y	18	25	Fell off	N	Fledged
KS02-2022	Stilt	Kawainui	WK/ff:OA	Y	26	29	Battery Failure	N	Fledged
HS03-2023	Stilt	Hāmakuā	AO:OY/ff	N	NA	21	NA	Y	Fledged
HS03-2023	Stilt	Hāmakuā	AO:OB/ff	Y	19	27	Fell off	N	Fledged
HS03-2023	Stilt	Hāmakuā	AO:KG/ff	N	NA	17	NA	N	Fledged
HS03-2023	Stilt	Hāmakuā	AO:SB/ff	N	NA	9	NA	N	Fledged
HS04-2023	Stilt	Hāmakuā	Turquoise	N	2	12	NA	Y	Predated: Mongoose
HS04-2023	Stilt	Hāmakuā	Orange	N	NA	2	NA	Y	Unknown mortality

HS04-2023	Stilt	Hāmakuā	Fuschia	N	NA	2	NA	Y	Unknown mortality
HS04-2023	Stilt	Hāmakuā	Blue	Y	5	7	Found on ground	Y	Unknown mortality
HS08-2023	Stilt	Hāmakuā	Blue	N	NA	1	NA	Y	Unknown mortality
HS08-2023	Stilt	Hāmakuā	AO:KR/ff	N	NA	7	NA	N	Fledged
HS02-2023	Stilt	Hāmakuā	AO:YK/ff	Y	21	35	Battery Failure	N	Fledged
HS02-2023	Stilt	Hāmakuā	WO/ff:AO	Y	8	22	Battery Failure	N	Fledged
HS11-2023	Stilt	Hāmakuā	RO/ff:AO	N	NA	13	NA	N	Fledged
HS11-2023	Stilt	Hāmakuā	LB/ff:AO	N	NA	8	NA	N	Fledged
HS11-2023	Stilt	Hāmakuā	SY/ff:AO	Y	18	22	Fell off	N	Fledged
HS09-2023	Stilt	Hāmakuā	AO:YP/ff	Y	25	30	Carcass found	Y	Unknown mortality
HS09-2023	Stilt	Hāmakuā	AO:LR/ff	N	NA	17	NA	N	Fledged
HS21-2023	Stilt	Hāmakuā	WS/ff:AO	Y	30	40	Signal stop working	N	Fledged
HG02-2023	Gallinule	Hāmakuā	Yellow	Y	9	9	Transmitter dead	NA	Unknown fate
HG02-2023	Gallinule	Hāmakuā	Blue	N	NA	1	NA	Y	Unknown mortality
HG02-2023	Gallinule	Hāmakuā	Mauve	Y	3	3	Transmitter on nest	NA	Unknown fate
HG07-2023	Gallinule	Hāmakuā	Blue	Y	10	10	Transmitter on nest	NA	Unknown fate
HG07-2023	Gallinule	Hāmakuā	Yellow	N	NA	1	NA	NA	Unknown fate
HG07-2023	Gallinule	Hāmakuā	Shamrock	N	NA	1	NA	NA	Unknown fate
HG08-2023	Gallinule	Hāmakuā	White	Y	6	3	Fell/pecked off	NA	Unknown fate
HG17-2023	Gallinule	Hāmakuā	Blue	Y	1	1	Signal stop working	NA	Unknown fate
HG17-2023	Gallinule	Hāmakuā	Yellow	N	NA	NA	NA	NA	Unknown fate
HG17-2023	Gallinule	Hāmakuā	Red	N	NA	NA	NA	NA	Unknown fate
HG17-2023	Gallinule	Hāmakuā	White	Y	4	4	Fell/pecked off	NA	Unknown fate
HG12-2023	Gallinule	Hāmakuā	Yellow	Y	4	4	Fell/pecked off	NA	Unknown fate

HG12-2023	Gallinule	Hāmakuā	Blue	N	NA	1	NA	NA	Unknown fate
HG12-2023	Gallinule	Hāmakuā	Red	N	NA	1	NA	NA	Unknown fate
HG12-2023	Gallinule	Hāmakuā	Turquoise	N	NA	0	NA	NA	Unknown fate
HG13-2023	Gallinule	Hāmakuā	White	Y	4	4	Fell/pecked off	NA	Unknown fate
HG13-2023	Gallinule	Hāmakuā	Orange	N	NA	1	NA	NA	Unknown fate
HG13-2023	Gallinule	Hāmakuā	Fuschia	N	NA	1	NA	NA	Unknown fate
HG11-2023	Gallinule	Hāmakuā	Yellow	Y	20	23	Fell off	N	Fledged
HG18-2023	Gallinule	Hāmakuā	Yellow	Y	1	1	Fell off	NA	Unknown fate
HG30-2023	Gallinule	Hāmakuā	Yellow	Y	6	6	Carcass found	Y	Unknown mortality
HG30-2023	Gallinule	Hāmakuā	Fuschia	N	NA	2	Carcass found	Y	Unknown mortality
HG26-2023	Gallinule	Hāmakuā	Shamrock	Y	1	1	Fell off	NA	Unknown fate
HG26-2023	Gallinule	Hāmakuā	Blue	N	NA	7	Fell off	NA	Unknown fate
HG24-2023	Gallinule	Hāmakuā	White	Y	2	2	Signal stop working	NA	Unknown fate
HG24-2023	Gallinule	Hāmakuā	Blue	Y	8	8	Fell off	NA	Unknown fate
HG28-2023	Gallinule	Hāmakuā	Fuschia	N	NA	0	NA	NA	Unknown fate
HG28-2023	Gallinule	Hāmakuā	Turquoise	Y	4	5	Fell off	NA	Unknown fate
HG28-2023	Gallinule	Hāmakuā	Yellow	Y	2	2	Fell off	NA	Unknown fate
HG29-2023	Gallinule	Hāmakuā	Hot pink	N	NA	1	NA	NA	Unknown fate
HG29-2023	Gallinule	Hāmakuā	Blue	Y	3	3	Carcass found	Y	Unknown mortality
HC05-2023	Coot	Hāmakuā	Mauve	Y	4	4	Signal stop working	NA	Unknown fate
KS01-2023	Stilt	Kawainui	Yellow	N	NA	1	NA	NA	Unknown fate
KS01-2023	Stilt	Kawainui	White	Y	8	8	Carcass found	Y	Unknown mortality
KS05-2023	Stilt	Kawainui	Yellow (2dots)	N	NA	1	NA	NA	Uknown fate
KS05-2023	Stilt	Kawainui	Light blue	Y	6	6	Fell off	NA	Uknown fate
KS05-2023	Stilt	Kawainui	Red	N	NA	0	NA	NA	Uknown fate
KS05-2023	Stilt	Kawainui	Blue	N	NA	0	NA	NA	Uknown fate

KS02-2023	Stilt	Kawainui	GB/ff:AO	Y	5	5	Signal stop working	NA	Uknown fate
KS02-2023	Stilt	Kawainui	Blue	N	NA	1	NA	NA	Uknown fate
KS06-2023	Stilt	Kawainui	Orange	N	NA	1	NA	NA	Uknown fate
KS10-2023	Stilt	Kawainui	AO:RR/ff	Y	8	11	Fell off	N	Fledged
UG01-2023	Gallinule	Ulupō	Blue	Y	1	1	Signal stop working	NA	Unknown fate
KG01-2023	Gallinule	Kawainui	Yellow	N	NA	2	NA	NA	Unknown fate
KG01-2023	Gallinule	Kawainui	Hot pink	N	NA	0	NA	NA	Unknown fate
KG03-2023	Gallinule	Kawainui	Shamrock	Y	7	7	Carcass found	Y	Unknown mortality
KG03-2023	Gallinule	Kawainui	White	N	NA	7	NA	NA	Unknown fate
KG03-2023	Gallinule	Kawainui	Orange	N	NA	5	Carcass found	Y	Unknown mortality
KG03-2023	Gallinule	Kawainui	Mauve	Y	1	3	fell/pecked off	NA	Unknown fate
KG03-2023	Gallinule	Kawainui	Yellow	Y	1	1	Signal stop working	NA	Unknown fate
KG04-2023	Gallinule	Kawainui	White	Y	7	7	Signal stop working	NA	Unknown fate
KG04-2023	Gallinule	Kawainui	Red	N	NA	1	NA	NA	Unknown fate
KG04-2023	Gallinule	Kawainui	Blue	N	NA	1	NA	NA	Unknown fate
KG04-2023	Gallinule	Kawainui	Shamrock	N	NA	1	NA	NA	Unknown fate
KG04-2023	Gallinule	Kawainui	Fuschia	N	NA	1	NA	NA	Unknown fate
KG05-2023	Gallinule	Kawainui	Yellow	N	NA	1	Carcass found	Y	Unknown mortality
KG05-2023	Gallinule	Kawainui	Red	N	NA	2	NA	NA	Unknown fate
KG05-2023	Gallinule	Kawainui	Shamrock	Y	3	3	Fell/pecked off	NA	Unknown fate
KG05-2023	Gallinule	Kawainui	Blue	Y	2	2	Carcass found	Y	Unknown mortality
UG01-2023	Gallinule	Kawainui	White	Y	1	1	Fell/pecked off	NA	Unknown fate
KG14-2023	Gallinule	Kawainui	Blue	Y	5	5	NA	NA	Unknown fate
KG14-2023	Gallinule	Kawainui	Red	N	NA	1	NA	NA	Unknown fate
KG14-2023	Gallinule	Kawainui	Yellow	N	NA	3	NA	NA	Unknown fate

KC01-2023	Coot	Kawainui	White	Y	8	8	Fell/pecked off	NA	Unknown fate
KC01-2023	Coot	Kawainui	Blue	N	NA	2	NA	NA	Unknown fate
KC01-2023	Coot	Kawainui	Hot pink	N	NA	1	NA	NA	Unknown fate
KC05-2023	Coot	Kawainui	White	Y	5	5	Carcass found	Y	Unknown mortality

[1]Chick fate was classified as "predation" if radio-tracking yielded convincing evidence of predation by a specific predator; "unknown predation" if the chick disappeared and radio-signal disappeared concurrently with circumstantial evidence of predation by a specific predator; and "unknown mortality" if the chick disappeared for unknown reasons.

Figure A.1.1 A logistic regression model showing the probability of nesting success as predator of mammals detection at nest increases among the three species (*Stilts* $n = 49$, *Gallinules* $n = 66$; Coots $n = 19$).

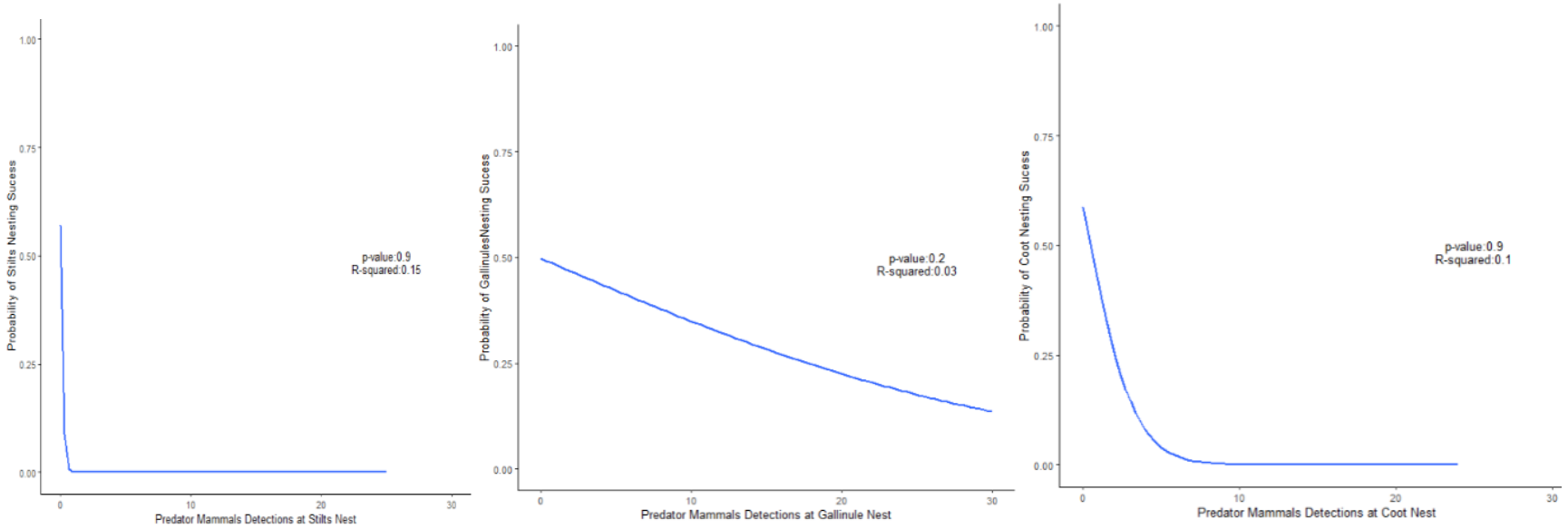

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Figure A.2.1 Linear regression model showing the proportion of eggs hatched as predator of mammals detection at nest increases of all three species (*Stilts n* = 49, *Gallinules n* = 66 ; Coots *n* = 19).

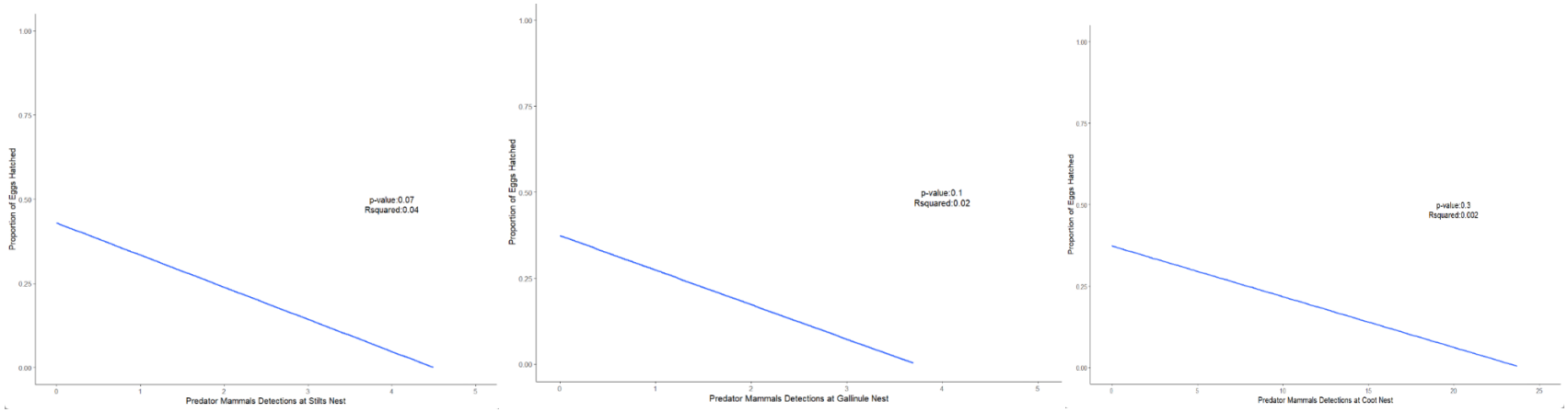
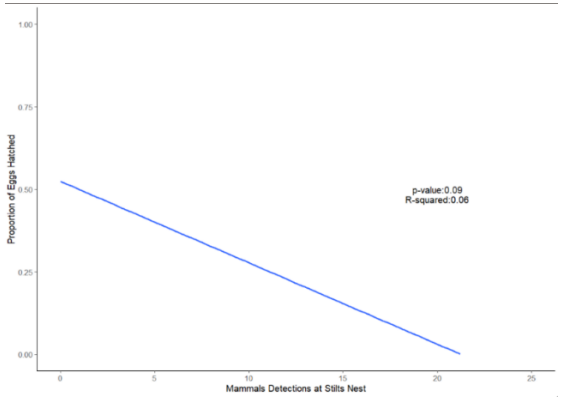
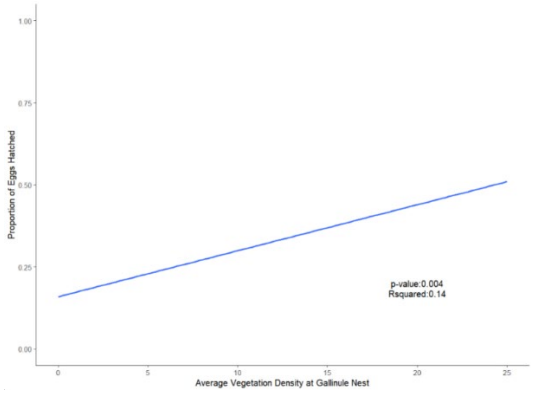


Figure A.3.1 Linear regression model showing the proportion of eggs hatched with vegetation parameters as predator of mammals detection at nest increases of among three species (*Stilts* n = 32, *Gallinules* n = 50 ; Coots n = 15).





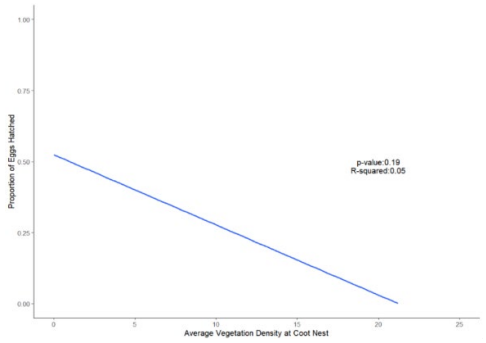


Figure A.4.1 Linear regression model showing the proportion of eggs hatched as mongoose detections at stilts nest increases (n=49).

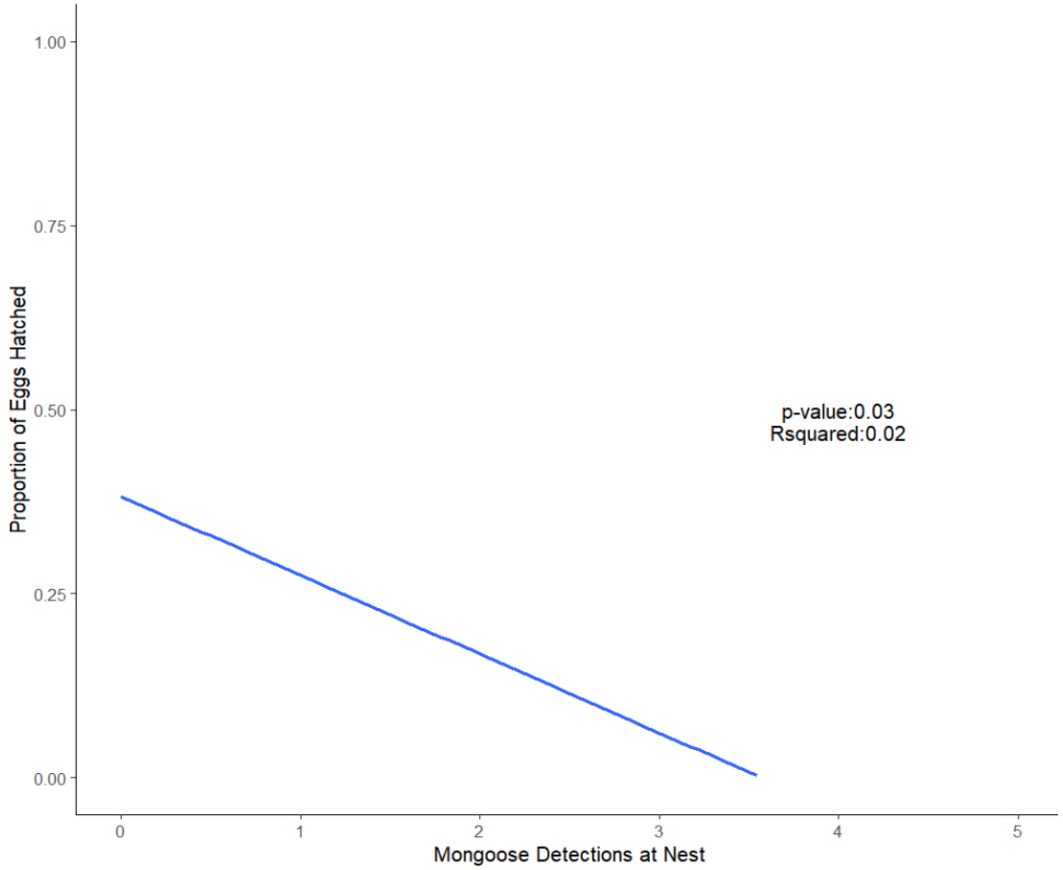


Figure A.5.1 Activity Density of diurnal ground birds detections at the nest (n= 13,763).

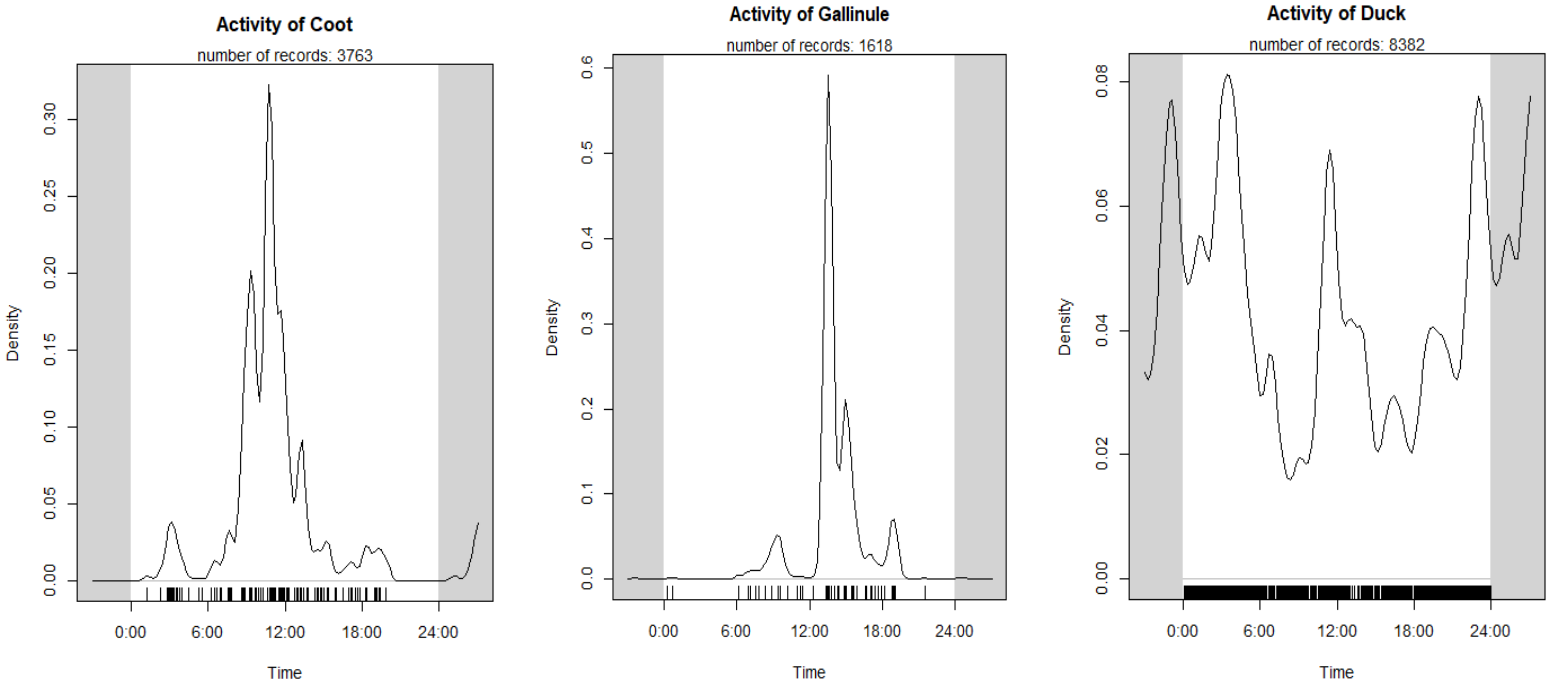


Figure A.6.1 Activity Density of nocturnal predator detections at the nest (n=872).

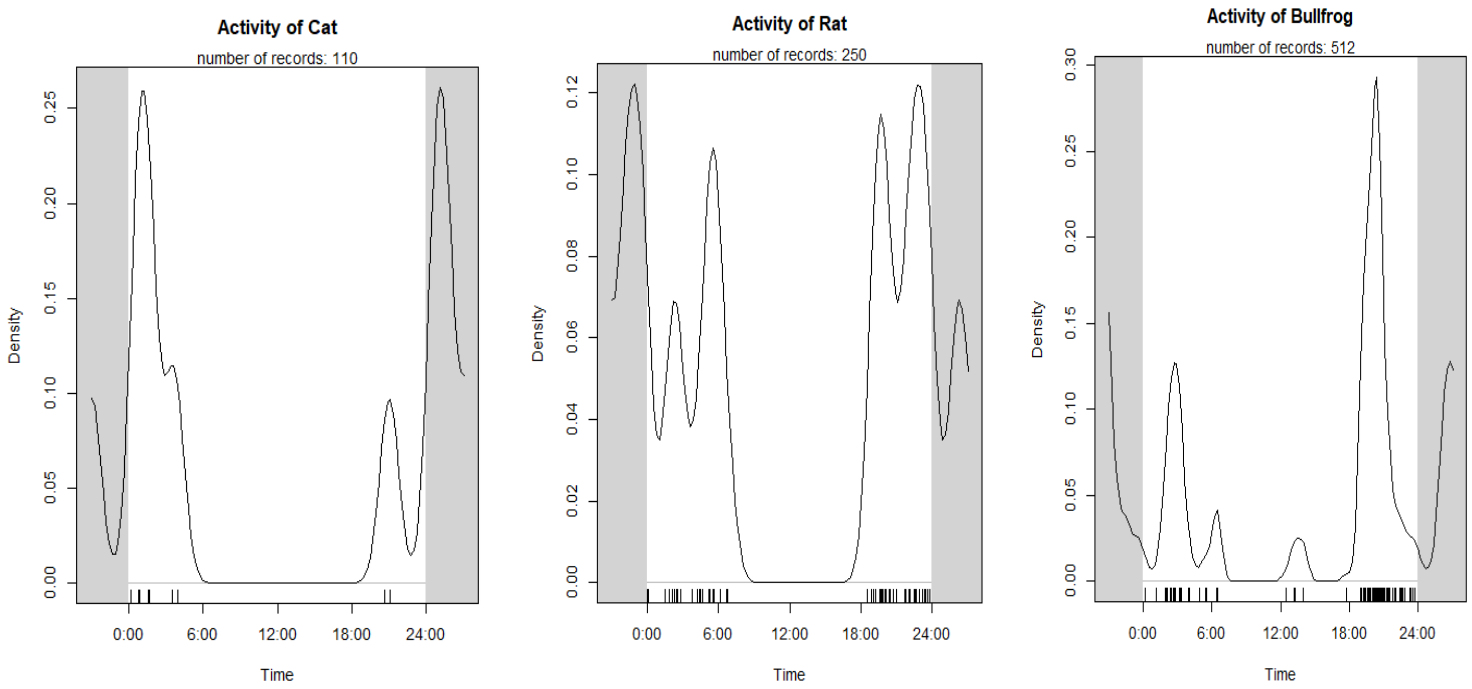


Figure A.7.1 Activity Density of diurnal predator detections at the nest (n=1,437).

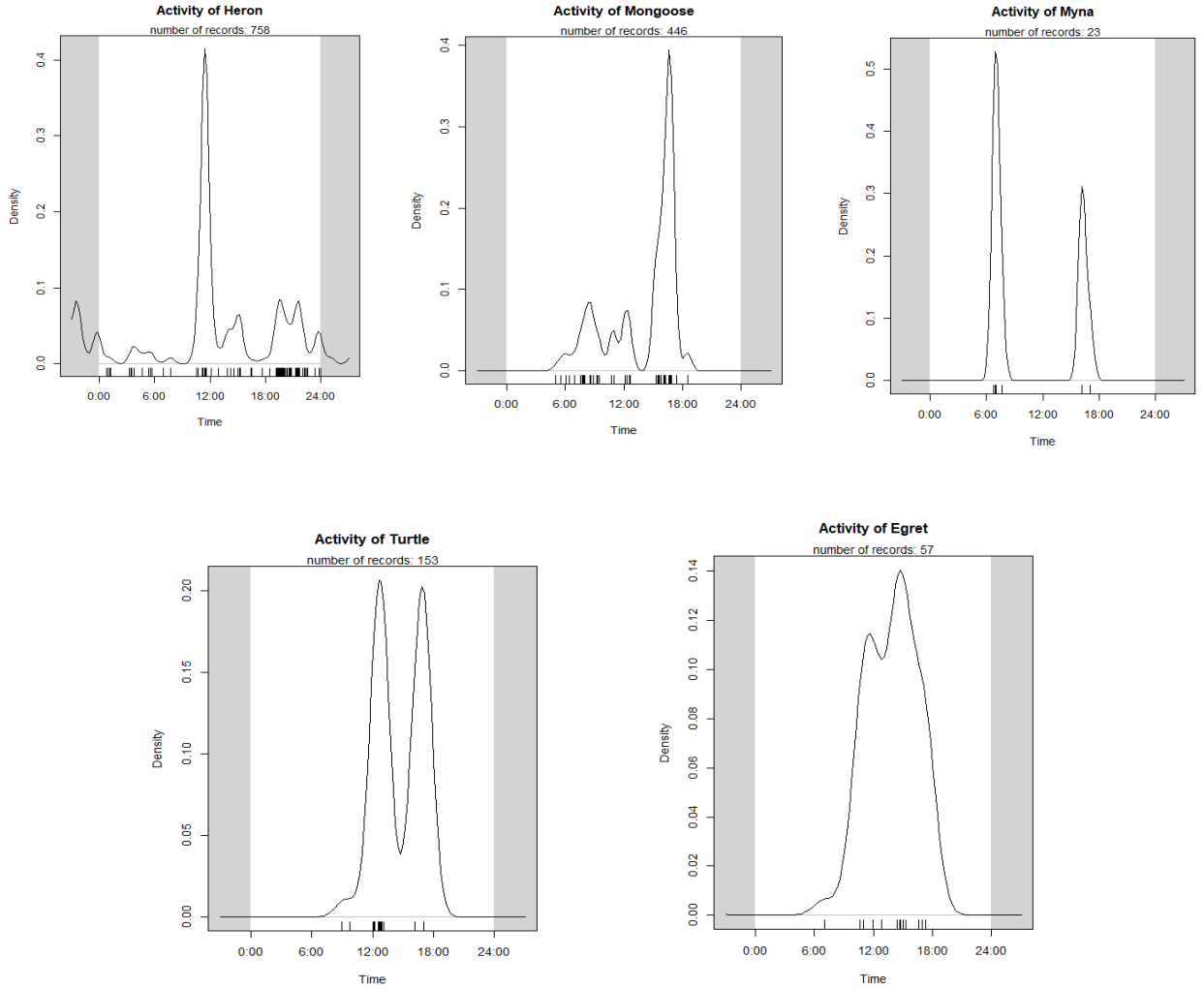


Figure A.8.1 A logistic regression model showing the probability of chick survival as predator of mammals detection at nest increases among the stilts and gallinule species (*n=49)*

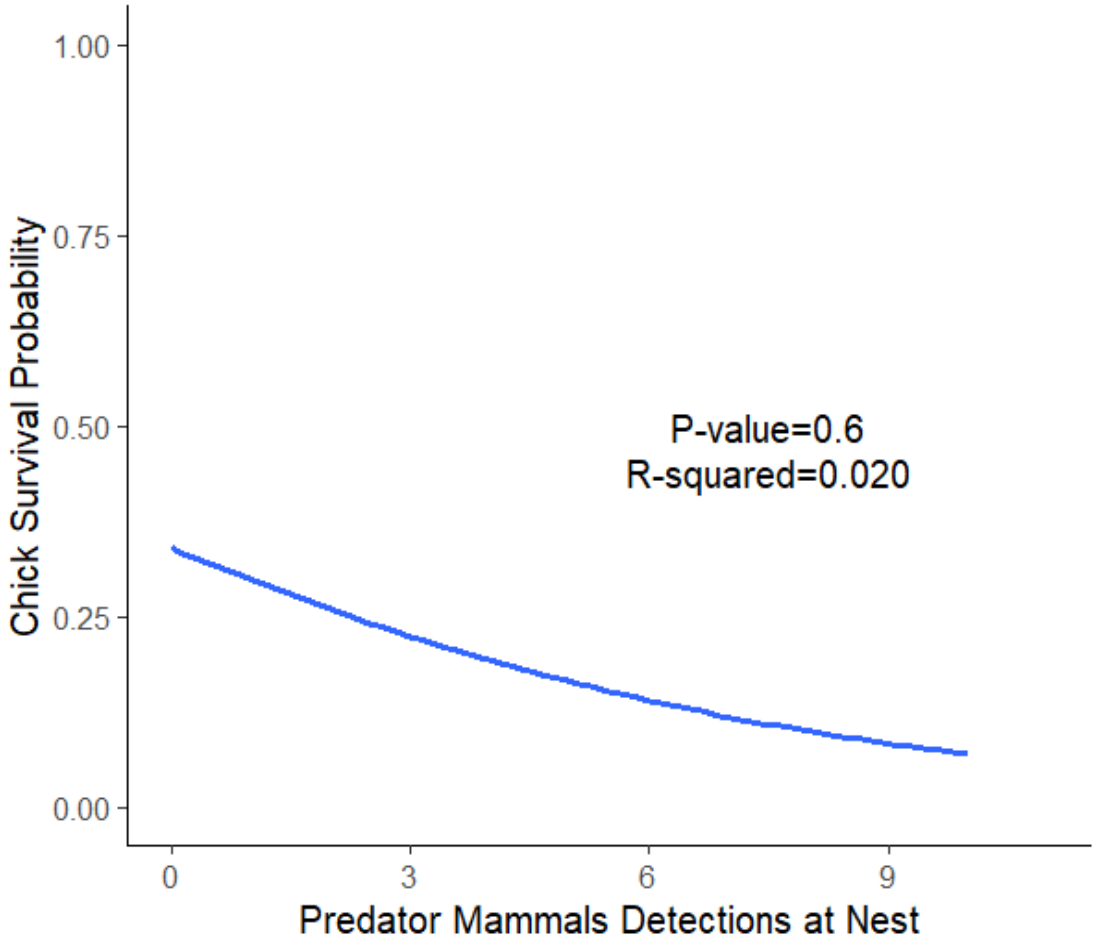


Figure A.9.1 A logistic regression model showing the probability of chick survival as vegetation density at nest increases (left) and as vegetation height at nest increase (right) among the stilts and gallinule species (n = 31).

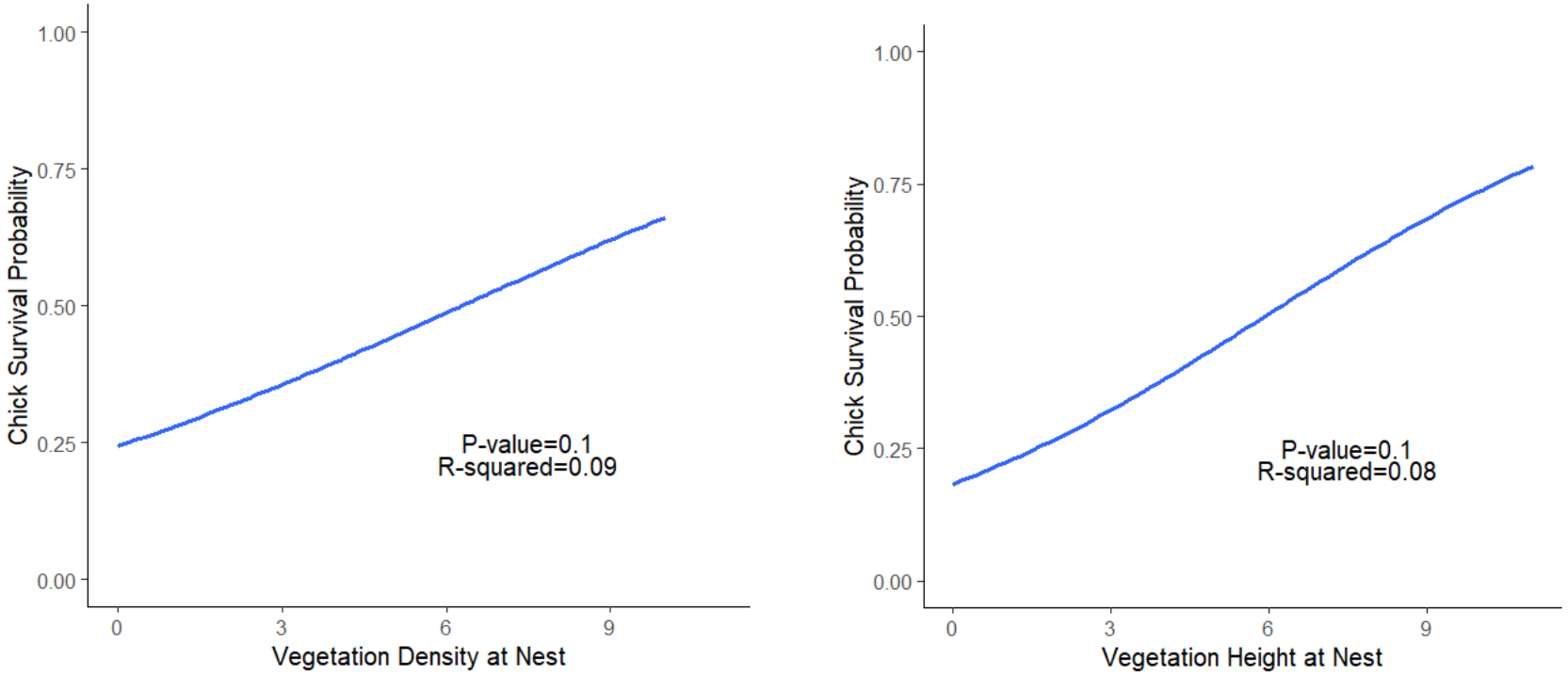
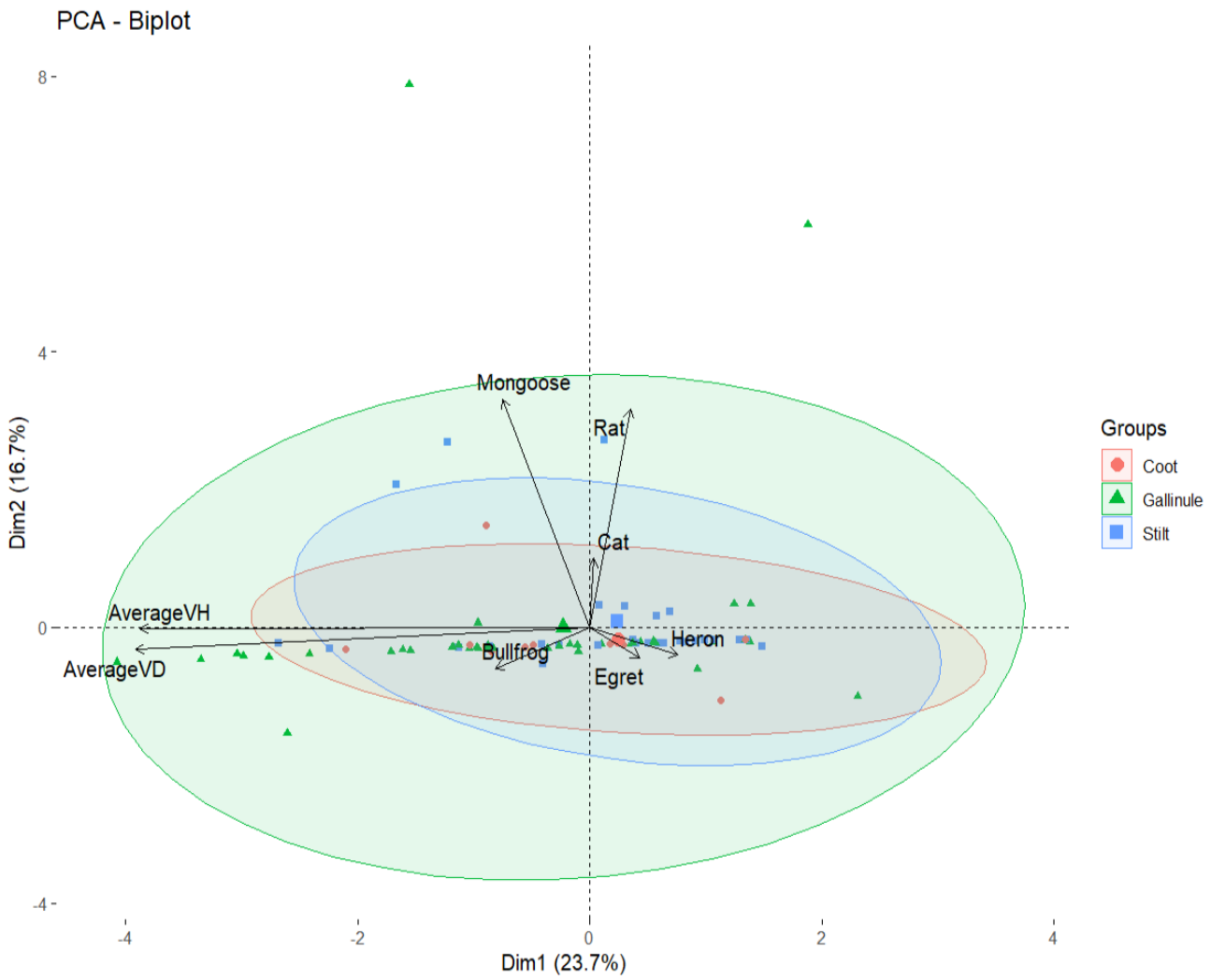


Figure A.10..1 A Principal Component Analysis (PCA) showing the relationship explanatory variables on this study.



APPENDIX B- Images of nest and chick predators at nest on Hāmakuā & Kawainui Marsh.

Image 1. Mongooses consume a chick of a Hawaiian gallinule nest at Kawainui Marsh.

Image 2 Mongooses consume an egg of a Hawaiian stilt nest at Hāmākua Marsh.

Image 3 Rat consume an egg of a Hawaiian gallinule nest at Hāmākua Marsh.

Image 4 Mongoose consume an egg of a Hawaiian coot nest at Hāmākua Marsh.

Image 5 Hawaiian coot destroy an egg of a Hawaiian stilt nest at Kawainui Marsh.

Image 6 (left to right): Bullfrog with stomach dissected to find radio-tag with a partially digested chick body parts such as the leg; Bullfrog with stomach dissected to find radio-tag (next to finger) at Kawainui Marsh. Photo credit: Lindsey Nietmann.

Image 7 (Left to Right) Radio Transmitter and recovered leg bands found on the ground from Hawaiian Stilt that went missing, suspected mongoose predation event. Carcass body parts remaining, as suspected mongoose predation on a stilt chick at Kawainui Marsh.

Image 8: Hawaiian Gallinule Adult Dead Body Carcass found on the ground 10 feet away from a gallinule nest at Hāmākua Marsh State Wildlife Sanctuary, suspected raptor predation event.