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Hāmākua Marsh State Wildlife Sanctuary

Waterbird Report, 2024

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I. Overview

Hāmākua Marsh State Wildlife Sanctuary (hereafter ‘Hāmākua Marsh’) is a 91-acre wildlife sanctuary designated for the recovery of federally and state-listed endangered waterbirds in Kailua, Hawaiʻi. Hāmākua Marsh is a seasonally brackish wetland on the windward side of the Koʻolau Range on the island of Oʻahu.

The U.S. Fish and Wildlife Service has identified Hāmākua Marsh as a ‘core’ wetland for the recovery of three endemic and endangered waterbirds: the Hawaiian Coot (*Fulica alai*), Hawaiian Common Gallinule (*Gallinula galeata sandvicensis*), and Hawaiian Stilt (*Himantopus mexicanus knudseni*; U.S. Fish and Wildlife Service, 2011). The Department of Land and Natural Resources, Division of Forestry and Wildlife (DOFAW) manages Hāmākua Marsh, intending to create breeding, foraging, and roosting habitat for three species of federally endangered waterbirds (hereafter ‘waterbirds’): Hawaiian Coot, Hawaiian Gallinule, and Hawaiian Stilt.

Hawaiian waterbirds are considered ‘conservation reliant,’ meaning that populations will require active management for the foreseeable future (Reed et al. 2012, Underwood et al. 2013). Wetland managers mitigate threats to Hawaiian waterbirds by controlling invasive plants and removing invasive predators. Monitoring the success of these strategies over time allows managers to adapt management actions to protect waterbirds most efficiently.

II. Habitat Management

Habitat Manipulations.—The wetland portion of Hāmākua Marsh is approximately 23.3 acres and comprises four basins. Basins A, B, C, and D vary in area (A: 4.6; B: 9.5; C: 6; D: 3.2 acres), and each offers different proportions of open water to vegetation or mudflat. The wetland is fed from rainfall and runoff from the adjacent 68-acre Puʻu o ʻEhu hillside. Water from the adjoining Kawainui Canal will flood the interior of the wetland during the rainy season or when the sand berm at Kailua Beach Park is removed, and the ocean tides result in a net increase in water level. The dominant vegetation within the wetland is pickleweed (*Batis maritima*) and saltmarsh bulrush (*Bolboschoenus maritimus*).

Habitat manipulations in 2024 included line trimming all of Basin A and using a skid steer and mulcher attachment to remove vegetation in the drier edges and accessible sections in Basin A, B, C, and D. This was the only time since 2018 that the habitat was altered once (Table 1). In 2019–2021, the habitat was selectively manipulated on three separate occasions while avoiding stilt nesting season (March-August); in 2022–2023, the habitat was manipulated twice.

Mechanical manipulation was incorporated to minimize the pickleweed (*Batis maritima*) and to promote the growth of the naturally occurring native seed bank, leaving islands of pickleweed habitat for nesting. Basin A was manipulated to provide 50:50 open water to vegetation in the wet season and a ratio of mudflat equal to water loss as it relates to the topography in the dry season. Basin B was manipulated to provide 70:30 open water to vegetation in the wet season and a ratio of mudflat equal to water loss as it relates to the topography in the dry season. Basins C and D were manipulated to promote more *Bolboschoenus maritimus* to replace the pickleweed.

Both Basins C and D were manipulated to provide 60:40 open water to vegetation in the wet season and a ratio of mudflat equal to water loss as it relates to the topography in the dry season. The frequency of habitat manipulations was needed to control vegetation regrowth in the mudflat areas.

Optimizing foraging and nesting habitat for waterbirds can be opposed, as improving foraging habitat may decrease nesting habitat. Gallinule nests (6) have been found in pickleweed (*B. maritima*) that had not been mechanically manipulated in 2019. Those six nests were found in pickleweed that was, on average, 45.5 cm above the water line. Those manipulations for optimizing foraging may include disking and tilling when planning habitat management for waterbirds in wetlands. Still, for areas where nesting is encouraged, pickleweed needs manipulation no more than once annually. Foraging for coots, gallinules, and stilts takes place in more open habitats, especially for stilts and coots, and to optimize foraging habitat, vegetation manipulations are recommended. During habitat manipulations, plant leaves are severed and decompose, providing detritus for food and structure for microorganisms, which provide food for macroinvertebrates, thus increasing invertebrate forage for waterbirds (Kaminski and Prince, 1981). Another study posited that aquatic invertebrate mass and diversity were most significant in habitats that offered more detrital matter (Gray et al., 1999). Manipulations of vegetation may increase macroinvertebrate availability but certainly increase accessibility to invertebrate prey when vegetation is thick (Gawlik, 2002; Chastant and Gawlik, 2018). The pickleweed in Hāmākua Marsh can grow densely when not mechanically manipulated, potentially prohibiting waterbirds from accessing prey.

Water Level and Salinity.—In 2024, water levels ranged from 12.0–22.2, 9.0–26.2, 10.8–18.6, and 8.4–15.6 inches in Basins A, B, C, and D, respectively (Figure 1). Water level readings were taken during waterbird surveys (*n* = 50). Salinity measurements were taken four times, ranging from 0–26, 0–24, 0–29, and 0–19 ppt in Basins A, B, C, and D, respectively (Figure 1).

III. Waterbird Monitoring

a. Waterbird Surveys

1. Methods

Surveys.—The Wildlife Biologist conducted weekly to semi-weekly surveys. Using the direct count method, a census technique was used to count all waterbirds present. Waterbird surveys were conducted using consistent observation lines to maintain consistency amongst observers. When conducting waterbird surveys, observers walked along the stream edge paralleling Hāmākua Drive from Basin A toward Basin D (intersection of Hāmākua Drive and Kailua Road). Basin A is on the southeast corner of the wetland, and Basin D is toward the northwest (Figure 5). Chicks and fledglings were recorded separately for each endangered wetland bird, and all banding information observed was recorded.

Observers also recorded ancillary environmental data: cloud cover, vegetation cover, rainfall, wind and gust speed, water level, and the degree of human influence. Cloud cover was estimated as a continuous percentage between 0 and 100 by tens. Vegetation cover was ranked in discrete categories from 0 to 3: 0 = open water, 1 = 26–50% cover, 2 = 51–75% cover, and 3 = ≥75% cover. Rainfall was recorded in discrete categories of 0 = no rain, 1 = mist or fog, 2 = drizzle, and 3 = light rain. Wind and gust speed were recorded as Beaufort categories: 0 = no wind, 1 = smoke drifts (4–7 mph), 2 = wind felt on face, and 3 = leaves, small twigs in constant motion (8–12 mph). Water level was recorded as a discrete category ranging from 0 to 3, where 0 = dry, 1 = lower than normal, 2 = normal, and 3 = higher than normal. Human impact ranged from 0 to 2: 0 = indirect, 1 = moderate, and 2 = heavy.

Habitat Use.—Microhabitat was assessed for all the endangered birds encountered. Microhabitat was identified as: *stream*, *stream bank*, *open mudflat*, *vegetation*, *0–3" water*, *3–6" water*, and *>6" water*. *Stream* is defined as stream water that is deeper than the tarsal-tibiotarsal joint (i.e., joint not visible) for stilts and water deep enough for the coot or gallinule to be swimming; *stream bank* is stream water not deeper than the tarsal-tibiotarsal joint (i.e., joint visible) in stilts, or coots and gallinules observed standing on vegetation inside the stream channel or in shallow enough water where swimming is not allowable; *open mudflat* is defined as exposed or bare soil with no emergent vegetation; *vegetation* is emergent vegetation with small pockets of mudflat or water present; *0–3" water* is water no deeper than the tarsal-tibiotarsal joint (i.e., joint visible) for stilts and walking in water for coots and gallinules; *3–6" water* is deeper than the tarsal-tibiotarsal joint (i.e., joint not visible) for stilts and swimming for coots and gallinules; and *>6" water* is such that no part of the leg is visible in the stilt, for the coot and gallinule depth of water was estimated by reading the nearest water gauge.

Fledging Success.—From 2005–2024, endangered waterbird fledging success was measured using the formula: (# of observed fledglings/# of observed chicks) x 100 = % fledging success. Fledglings and chicks were mapped in each survey to aid in identifying each brood's chicks-to-fledging ratio. In addition to using the above formula for fledging success, fledging success was measured using the formula: (# of observed fledglings/# of broods) = ratio of fledglings per brood. The alternative formula for fledging success should aid in reducing the overestimating of fledging success because all chicks from a single brood are seldom observed. The likelihood of observing one brood is greater than observing all chicks from a single brood. Furthermore, the USFWS was documented using this method in the Kahuku Wind Power Habitat Conservation Plan (SWCA, 2010). Therefore, fledging success data can more easily be compared to other sites. The older method of calculating fledging success will also be used to continue comparisons from previous years.

2. Results

Surveys.—A total of 50 surveys were conducted at Hāmākua Marsh in 2024. Mean abundances (range) for coots were 20.4 individuals (10–35), gallinules were 32.1 individuals (13–53), and stilts were 28.0 (8–57) individuals per survey (Figure 2). The average abundances of coots, gallinules, and stilts were highest in Basins B, B, and C, respectively (Figure 3). The average density of coots, gallinules, and stilts per acre was highest in Basins C, C, and C, respectively. The average endangered waterbird per acre was 3.5 individuals.

Habitat Use.—Habitat utilization differed by species. The Hawaiian Coot was found most often in streams, with 36.4% of the observations; the Hawaiian Gallinule was found most often in vegetation, with 56.5% of the observations; and the Hawaiian Stilt was found most often in 0–3" water, with 64.7% of the observations (Figure 4). Coots utilized deeper water habitats, gallinules used vegetation, and stilts used shallow water and mudflats.

Fledging Success.—Fledging success in Hāmākua Marsh State Wildlife Sanctuary from 2020 to 2024 ranged from 0–63%, 13–49%, and 27–73% for coots, gallinules, and stilts, respectively. For 2024, coots, gallinules, and stilts had an overall fledging success rate of 6%, 31%, and 29%, respectively (Table 2). The fledging success rate in 2024 for coots, gallinules, and stilts was below their pooled averages of 55%, 65%, and 62%, respectively. Coot fledgling recruitment was one fledgling, below-average recruitment for coots. The annual average recruitment for coots was 5.8 fledglings per year. Gallinule's fledging recruitment was 40 fledglings, above the average yearly recruitment of 35.3 fledglings per year. Stilt fledging recruitment was eight fledglings, below the average recruitment of 12.4 fledglings per year.

3. Recommendations

Chick survival estimates are labor intensive and require daily observations of marked chicks. Alternatively, in 2025, Lukacs's brood survival estimates will be modeled to achieve a brood survival statistic that will more accurately inform the Wildlife Biologist of fledgling survival. In addition,

b. Nest Surveys

1. Methods

Nest Monitoring.—Nests were located during routine weekly or biweekly surveys using an area-search survey. During area-search surveys, 3−7 observers walked meandering transects to locate all nests in each area. When conducting waterbird nest surveys, observers walked the marsh beginning in Basin A and continued toward Basin D until the wetland was thoroughly searched (Figure 5). During the non-stilt nesting season, the focus was on searching coot and gallinule nest habitats.

Waterbird nests were monitored from January through December 2024. Nest success was monitored using Spypoint Solar Dark (GG Telecom, Quebec, Canada) and Reconyx Hyperfire 2 (Reconyx Inc., Wisconsin, USA) passive infrared cameras placed about 1 m from the nest, mounted on a 7.6-cm wide metal post 1.8-m long, fixed with a fully-adjustable camera mount that allows a camera angle of 0–90°. Cameras were programmed to take two images back-to-back immediately upon infrared motion activation. Cameras were programmed to take photos instantly for each activation (Instant setting recovery speed: 0.3s). Cameras were checked weekly for battery life and SD card data retrieval. They were removed immediately after a nest was confirmed failed or after it was confirmed successful (coot and gallinule nest cameras remained for 7 days post-hatch).

Reproductive Success.—Reproductive metrics were used to determine nest, fledging, and overall reproductive success for coots, gallinules, and stilts. *Nest Success* was determined by using the formula: (# of broods observed/# of nests observed)*100 = % nests that hatched ≥1 chick;

Fledging Success was determined by using the formula: (# of broods that produced ≥1 fledgling/# of broods observed)*100 = % of broods that produced ≥1 fledgling; and *Overall Reproductive Success* was determined using the formula: (# of broods that produced ≥1 fledgling/# of nests observed)*100 = % of nests that produced ≥1 fledgling.

2. Results

Nest Monitoring.—Forty-six nest surveys were conducted from January through December 2024. Nests were found in February–July for Hawaiian Coot, January–August for Hawaiian Gallinule, and April through June for Hawaiian Stilt. From January through December 2024, 14 coot, 40 gallinule, and 14 stilt nests were observed (Figure 6). Out of 68 nests observed, Basin B contained the most nests (n = 29), followed by Basin A (n = 15), Basin C (n = 14), and Basin D (n = 10). Coot nests were found most often in Basin B (58%); gallinule nests were found most often in Basin B (44%); and stilt nests were most often found in Basin C (36%; Figure 6).

<u>*Overall Nest Outcomes*</u>
Out of 68 nests discovered, 68% (n = 46) produced at least one chick, 12% (n = 8) failed due to predation or partial predation, 7% (n = 5) failed due to flooding, 10% (n = 7) failed due to abandonment, and 3% (n = 2) failed for unknown reasons. (Table 3).

<u>*Outcomes of Nests Monitored with Cameras*</u>
Of 68 nests, 53 (80%) had a camera placed on them. Cameras were placed on 57%, 83%, and 86% of coot (n = 8), gallinule (n = 33), and stilt (n = 12) nests, respectively.

Reproductive Success.—We observed 50 coot, 197 gallinule, and 55 stilt eggs. Seventeen, 127, and 28 chicks hatched from those coot, gallinule, and stilt eggs, respectively (Figure 7).

3. Discussion

Nest Monitoring.—In a study by Works et al. (2024), nest success estimates for coots, gallinules, and stilts from 2020-2023 at Hāmākua Marsh were 50%, 50%, and 47%, respectively. In 2024, nest success estimates were 26%, 61%, and 62% for coots, gallinules, and stilts, respectively. The study suggests that 2024 coot nest success was low, and gallinule and stilts nest successes were higher than in 2020-2023 (Works et al., 2024).

<u>*Outcomes of Nests Monitored with Cameras*</u>
Of nest failures, 15 of 20 (75%) failed due to predators or abandonment. A coot, mongoose, rat, and stilt were responsible for predating one nest each; the other four nests failed due to an unknown predator. Abandoned nests were incubated to full term and contained inviable or undeveloped eggs in two of seven abandoned nests; the other five were abandoned for unknown reasons.

Reproductive Success.—The proportion of eggs to chicks for coots, gallinules, and stilts was 34%, 64%, and 51%, respectively. The overall production is extremely low for all species (2%, 20%, and 15%, respectively), meaning that this population of waterbirds acts as a population sink rather than a cornerstone of productivity for the statewide population.

4. Recommendations

Nest Monitoring.—Weekly surveys are needed to observe all the nests throughout the nesting season and are recommended to continue. In 2025, nest surveys will be conducted bi-weekly for the entire year and weekly for peak nesting season. All active nests will be checked twice per week.

Approximately 75% of nests had a camera placed to monitor the nest fate, and in 98% of all waterbird nests, fate could be determined due to frequent twice-weekly nest checks. However, in an additional 2% of nests, the fate could only be determined as a failure with an unknown cause. The nests without a camera had incomplete clutches upon discovery, and upon subsequent visits, the eggs were missing or destroyed.

In the future, nests with camera data will be used to monitor nest success. Alternatively, nest success could be reported with the following formula: (# of observed broods/(# of observed nests - # of unknown nest fates)) x 100 = % nest success. This formula may report an underestimate of nest success if entire broods perish before being observed but could serve as a metric of nest success if camera availability or time is insufficient during the reporting year. Camera data remains the best option for reporting accurate nest success data.

c. Chick Surveys

1. Methods

Chick Monitoring.—Once chicks hatched, the maximum number of chicks for each nest was recorded and considered during weekly observations to be included in brood survival. Hatched chick counts were obtained through nest camera data. The Lukacs brood survival model (Program MARK, Lukacs Young Survival from Marked Adults) was used to analyze brood survival for the Hawaiian Gallinule. Lukacs' brood survival model estimates chick survival through brood observations instead of individual chick observations. To obtain chick observations, each chick would need a radio tag to be located daily, which is too labor intensive. Chick surveys were conducted during regular waterbird surveys, and on occasion, a separate brood survey was undertaken to create additional observation opportunities until through the fledgling period of >50d. The Hawaiian Stilt and Hawaiian Coot were not analyzed using Lukacs' brood survival model; however, chicks were recorded during the same observation periods using the same methods. Hawaiian Stilt chicks were banded and observed through the fledgling stage with an actual survival proportion that did not need estimation using a model. The Hawaiian Coot had too few observations of chicks using direct visual surveys.

2. Results

Chick Monitoring.—The Hawaiian Coot had one fledgling out of 17 chicks, 6% fledgling survival. The Hawaiian Gallinule had 40 fledglings out of 127 chicks, 31% fledgling survival. The Lukacs brood survival analysis for Hawaiian Gallinule estimated the probability of survival from hatch to fledgling (50d) was 40.3%. The Hawaiian Stilt had eight fledglings out of 28 chicks, 29% fledgling survival (Figure 7). One stilt chick carcass was found, and its remains suggested a Barn Owl (*Tyto alba*) predation (Figure 8).

Reproductive Success.—We observed seven coot, 29 gallinule, and 10 stilt broods; 1 coot, 19 gallinule, and five stilt broods produced ≥1 fledgling (Table 4). The number of broods observed per nest was 0.5, 0.8, and 0.7 for coots, gallinules, and stilts, respectively. The number of fledglings per brood was 0.1, 1.4, and 0.8 fledglings for coots, gallinules, and stilts, respectively. The number of fledglings per nest was 0.1, 1.1, and 0.6 fledglings for coots, gallinules, and stilts, respectively (Figure 7, Table 4).

3. Discussion

Chick Monitoring.—From 2020–2024, the coot, gallinule, and stilt had an average fledgling success of 37%, 28%, and 48%, respectively. The coot and stilt fledgling success was below average, but the gallinule fledgling success was average. The Lukacs brood survival model estimated a higher survival success than our chicks-to-fledgling ratio for gallinules; however, our apparent brood survival (broods that fledged ≥1 chick) was estimated at 66%, and the Lukacs estimate was 40%. For gallinules, the Lukacs model estimated survival probability between the chick to fledgling proportion and apparent brood survival estimate. The Lukas model provides an estimate that could have more accuracy than our estimate of our chick to fledgling proportion. The main reason is the difficulty of observing gallinule broods that frequent areas closer to the interior road. During our observations using cellular-enabled passive infrared cameras, we observed gallinule chicks from broods that were never observed during our routine surveys. To conclude, we likely underestimated our chicks-to-fledgling proportion of 40 fledglings of 127 chicks; the Lukacs estimate suggests about 51 fledglings from an available 127 chicks.

Reproductive Success.—The average chick per brood for coots, gallinules, and stilts from 2020–2024 at Hāmākua Marsh was 0.6, 5.9, and 3.1, respectively. In 2024, coots had 0.3 chicks per brood, gallinules had 4.4 chicks per brood, and stilts had 2.8 chicks per brood. Chicks per brood observed were below average for coots, gallinules, and stilt. The average fledglings per brood for coots, gallinules, and stilts from 2020-2024 at Hāmākua Marsh was 0.8, 1.4, and 1.4, respectively. In 2024, coots had 0.1 fledglings per brood, gallinules had 1.4 fledglings per brood, and stilts had 0.8 fledglings per brood. Fledglings per brood were below average, average, and below average for coots, gallinules, and stilts, respectively.

4. Recommendations

Chick Monitoring.—In 2025, we will monitor chicks using cellular-enabled passive infrared cameras, especially for broods in the wetlands' deeper reaches relative to the survey route along the business side of Kawainui Stream.

d. Long-term Waterbird Population and Productivity Analysis

1. Results

Waterbird Survey.—A total of 360 waterbird surveys were conducted during 2017–2024 (*n*=25, *n*=44, *n*=45, *n*=49, *n*=50, *n*=47, *n*=50, *n*=50, respectively). The average coot abundance for those years was 14, 17, 30, 40, 35, 24, 21, and 20 individuals; the average gallinule abundance was 69, 54, 72, 82, 57, 34, 29, and 32 individuals; and the average stilt abundance was 20, 26, 40, 46, 41, 33, 33, and 28 individuals, respectively (Figure 9).

Reproductive Productivity.—From 2020–2024, the number of nests correlated to the number of chicks and fledglings for coots and gallinules. In 2021, gallinule fledgling recruitment was lower than expected, considering many chicks. However, the number of stilt chicks was lower in 2023 due to mongoose predation of nests, resulting in fewer chicks relative to the number of nests. Fledgling recruitment was low in years with more hatched chicks compared to years with fewer chicks (2021 and 2024; Figure 10).

2. Discussion

The populations of coots, gallinules, and stilts at Hāmākua Marsh increased from 2018–2020 and decreased from 2021–2024 (coots and stilts decreased by 5% and 16% from 2023 to 2024, respectively), except for gallinules, which increased by 10% from 2023 to 2024. The cause of the decrease in coot and stilt populations was unknown, but it could have been due to the emigration of waterbirds to nearby wetlands. An increase in fledgling success spurred the population increase in gallinules.

3. Recommendations

In the last three years, we have continued to experience a long-term decline in population averages for coots, gallinules, and stilts. All three species are below their pooled averages from 2017–2024, but gallinules are 2.6x lower than their peak. In 2025, the focus will be on applying backpack GPS transmitters to gallinules. In 2025, 20 gallinules and 20 ducks will be outfitted with GPS transmitters to track their movements and capture potential mortality events.

IV. Predator Control

a. Methods

In 2024, DOC-200 kill traps (*n* = 16) and conibear cat-kill traps (*n* = 11) were deployed for 7,807.5 trap days. Conibear traps were increased from one to 11 in April, and DOC-200 traps were increased from 16 to 39 in December. The new conibear traps were distributed along the interior road, paralleling the marsh, and the new DOC-200 traps were deployed on the hill adjacent to the wetland (Figure 11). The DOC-200 and conibear traps were mounted inside housings to protect the trap mechanism from the elements and eliminate incidental take of non-target species. The DOC-200 and conibear traps were baited weekly to monthly with dry cat food mixed with salmon, shellfish, or crayfish oil. All traps were checked weekly and left open always.

b. Results

DOFAW trapped 51 small Indian mongooses (*Urva auropunctata*), 73 rats (*Rattus* spp.), and 15 cats (*Felis catus*; Table 5).

c. Recommendations

Mongooses trapped in 2024 were well below the annual average mongoose take from 2007–2019 (127 mongooses). DOFAW changed trapping techniques from contracted live trapping efforts to in-house trapping using kill traps in June 2020. During 2021-2024, the average annual mongoose captures were 46 individuals.

Despite the lower trapping success of mongooses in prior years utilizing live trapping techniques, DOC-200 kill traps and Tomahawk live traps showed no statistically significant difference in trapping success; however, DOC-200 traps outperformed live traps in our study (Roerk et al., 2022). Predator control using Goodnature A18 multi-kill traps in 2024 captured four mongooses in about 3,000 trap days. The Goodnature A18 multi-kill traps are ineffective and will not be used to control mongoose in 2025.

In 2024, at Hāmākua Marsh, known nest predations by mongooses accounted for three nest depredations. Comparatively, in 2023, there were 13 nest depredations by mongooses. In 2024, there was a 4.3 times decrease in mongoose nest predations.

V. Conclusions and Goals for 2024

Hāmākua Marsh provides adequate habitats for all endangered waterbirds present on Oʻahu. While Hāmākua boasts an annual production of coots, gallinules, and stilts in the form of fledglings, the relatively small size of the wetland portion of Hāmākua Marsh limits the ability of the marsh to sustain the endangered waterbirds on the island of Oʻahu and severely limits the marsh's ability to sustain Hawaiʻi. Increasing the functionality of the marsh to provide growing numbers of coots, gallinules, and stilts remains the most significant priority to managers of Hāmākua Marsh.

Waterbirds have many threats that impact the survivorship of their nests. Current studies cannot allocate any one threat as a source of nest loss at Hāmākua. Future studies should consider the same potential threats to the chick stage of the waterbird life cycle. In 2025, we will continue nest monitoring with cameras to inform the Biologist on predator control efficacy. The Biologist will continue intensive monitoring and apply backpack GPS transmitters to Hawaiian Gallinule and Hawaiian Duck hybrids to better understand their movements and possible mortality events. In addition, more effort will be used to increase predator control for cats and mongooses. The mongoose control project studying Goodnature A18s will continue, and we will determine the effect of placebo fish sausage on capture rates.

VI. Literature Cited

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VII. Appendix

a. List of Figures and Tables

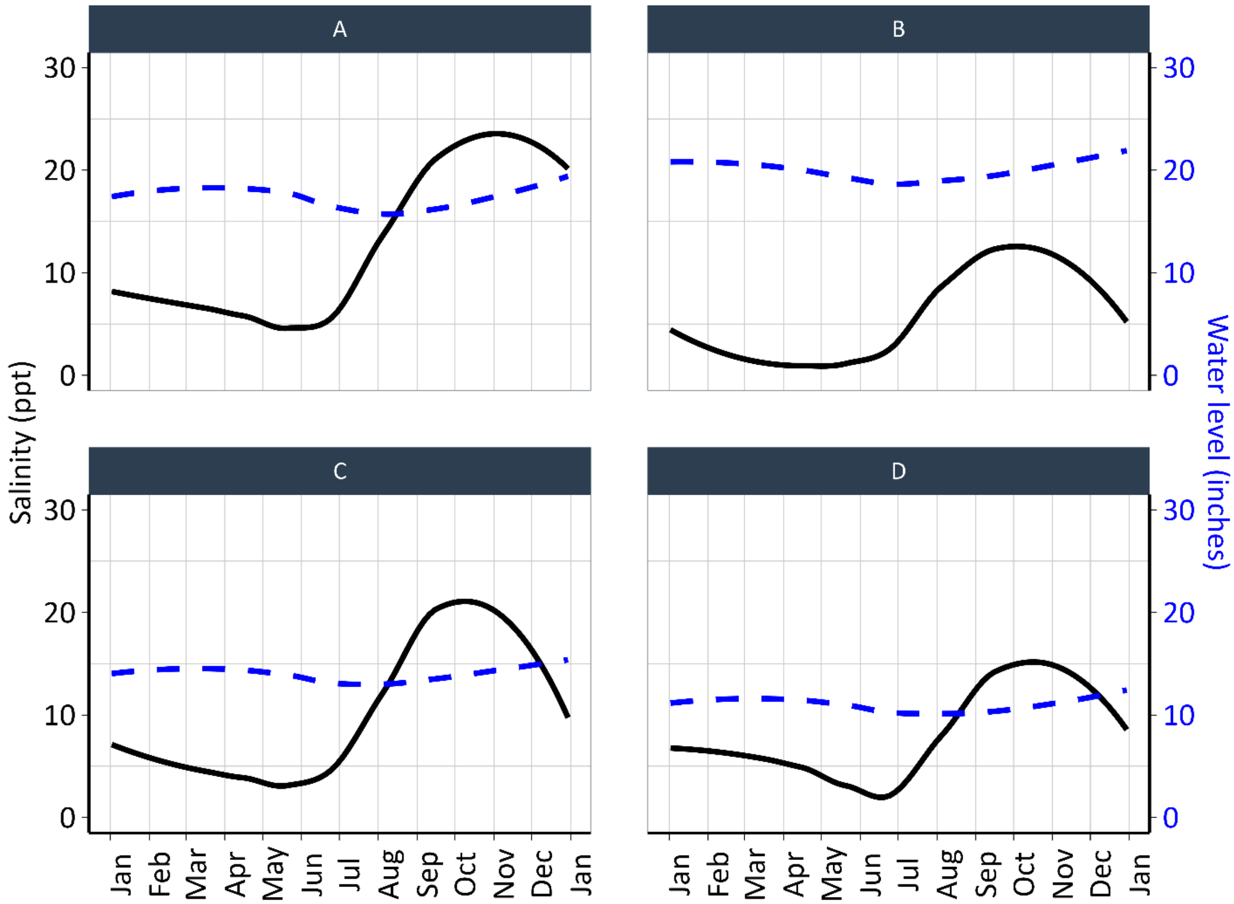

Figure 1. Water level and salinity in Basins A, B, C, and D in Hāmākua Marsh State Wildlife Sanctuary on O‘ahu, Hawai‘i, as measured in 2024. The blue dashed line is water level, and the solid black line is salinity.

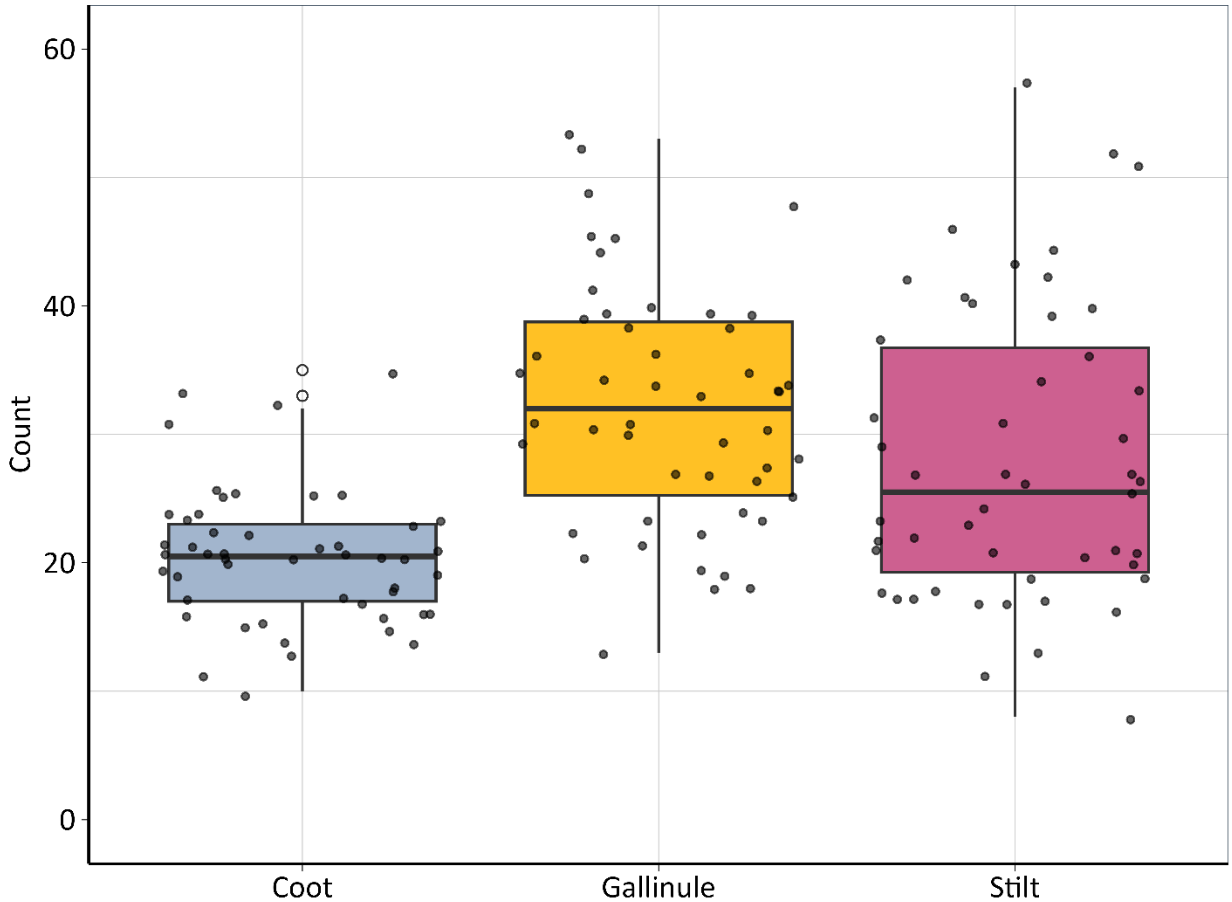

Figure 2. Boxplot displaying median values and interquartile ranges for coots, gallinules, and stilts in Hāmākua Marsh State Wildlife Sanctuary on Oʻahu, Hawaiʻi. Black points represent abundance for each survey (*n* = 50) in 2024. Open circles are outliers, and whiskers represent the minimum and maximum population counts.

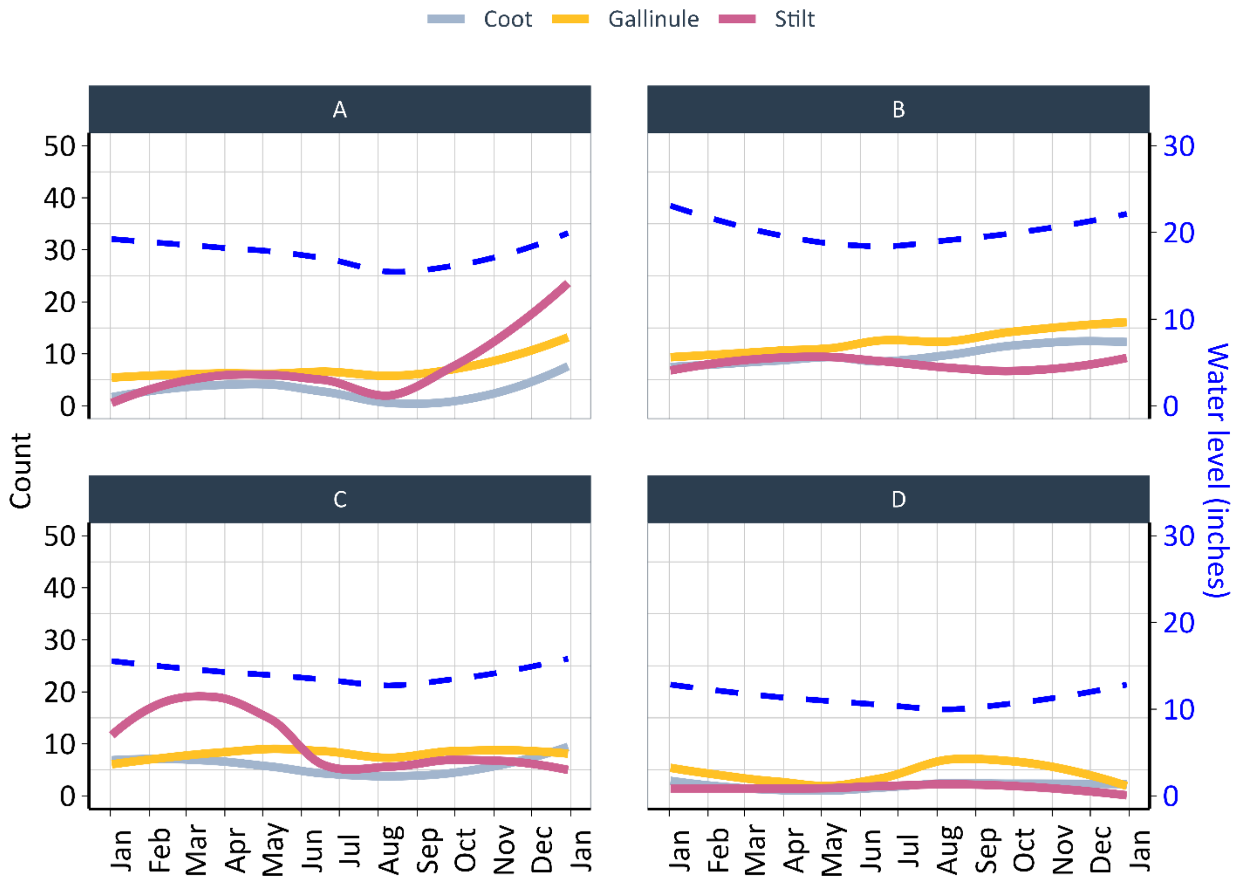

Figure 3. Waterbird abundance by for coots, gallinules, and stilts in basins A, B, C, and D at Hāmākua Marsh State Wildlife Sanctuary on O‘ahu, Hawai‘i during 2024. The blue dashed line is the water level in inches.

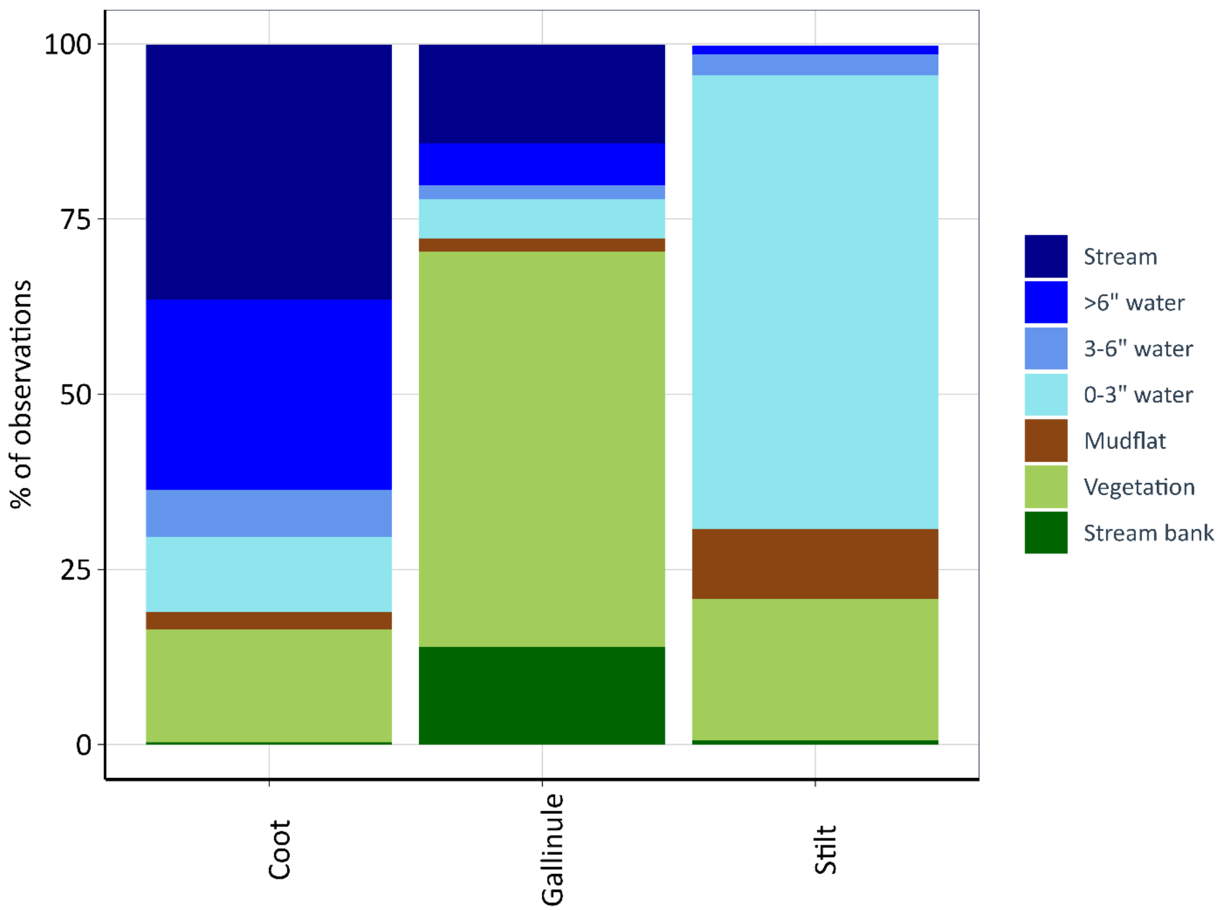

Figure 4. The proportions of observations for coots, gallinules, and stilts in seven microhabitats found within Hāmākua Marsh State Wildlife Sanctuary on O‘ahu, Hawai‘i in 2024.

Figure 5. Nest distribution map for Hāmākua Marsh State Wildlife Sanctuary. Pictured are 12 coot (A-2, B-7, C-3, D-0), 40 gallinule (A-11, B-15, C-8, D-6), and 14 stilt (A-2, B-4, C-5, D-3) nests observed in 2024. Nest surveys were conducted weekly and biweekly.

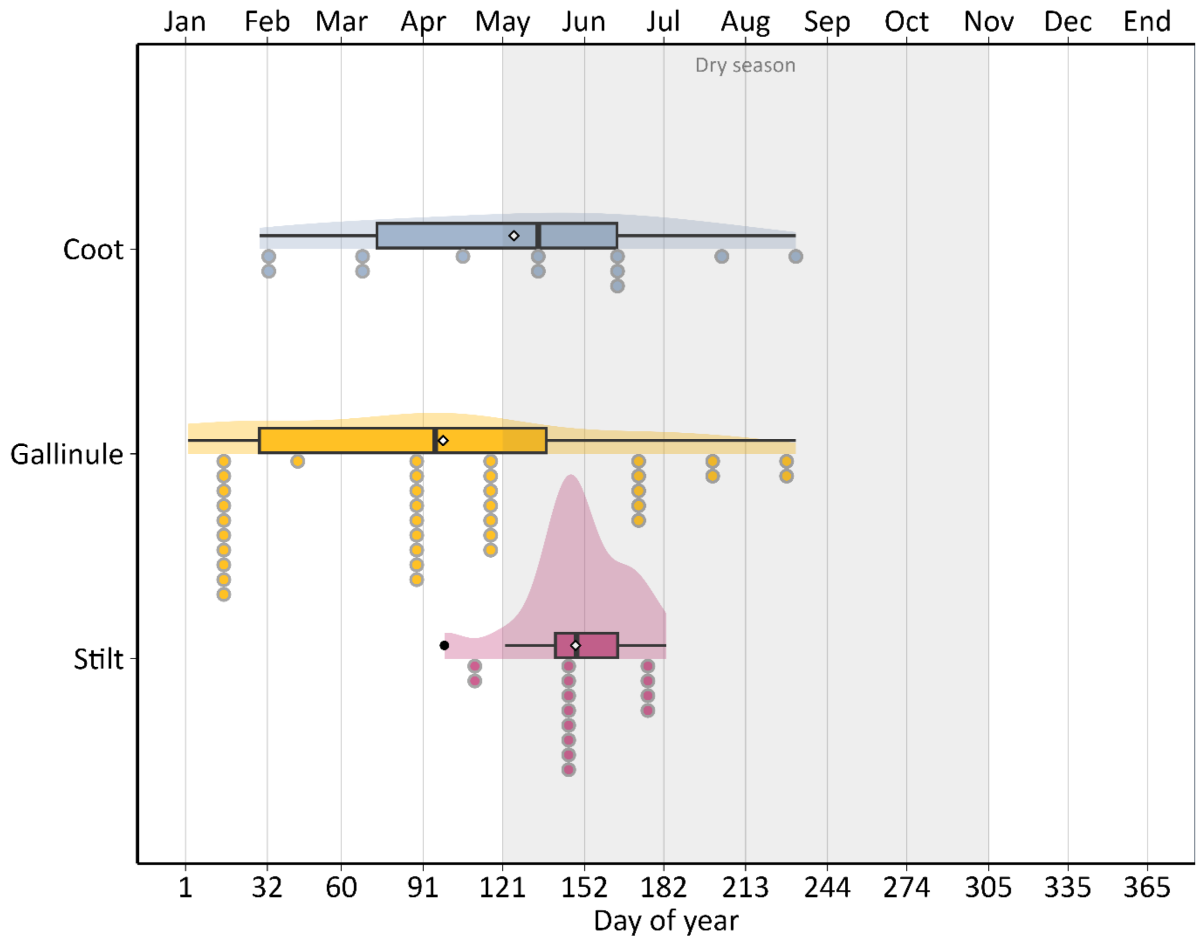

Figure 6. Raincloud plot of nest discovery dates for Hawaiian Coot (*Fulica alai*), Hawaiian Common Gallinule (*Gallinula galeata sandvicensis*), and Hawaiian Stilt (*Himantopus mexicanus knudseni*) at Hāmākua Marsh State Wildlife Sanctuary in 2024. The violin plots display the distribution and density of data; the boxplots represent the summary of statistics like the medians (bold vertical lines) and means (white diamonds) within the rectangles (25th to 75th percentiles) attached to the whiskers (minimum and maximum); outliers are represented as black points. The dot plots represent the raw data (minor points underneath the violin plots) that coincide with individual nest discovery days. The gray shading demarcates the dry season. Nest surveys were conducted weekly until no nests were discovered for four consecutive weeks, then bi-weekly checks were initiated. Weekly checks were resumed once wetland water levels were significant enough to spur nest initiation.

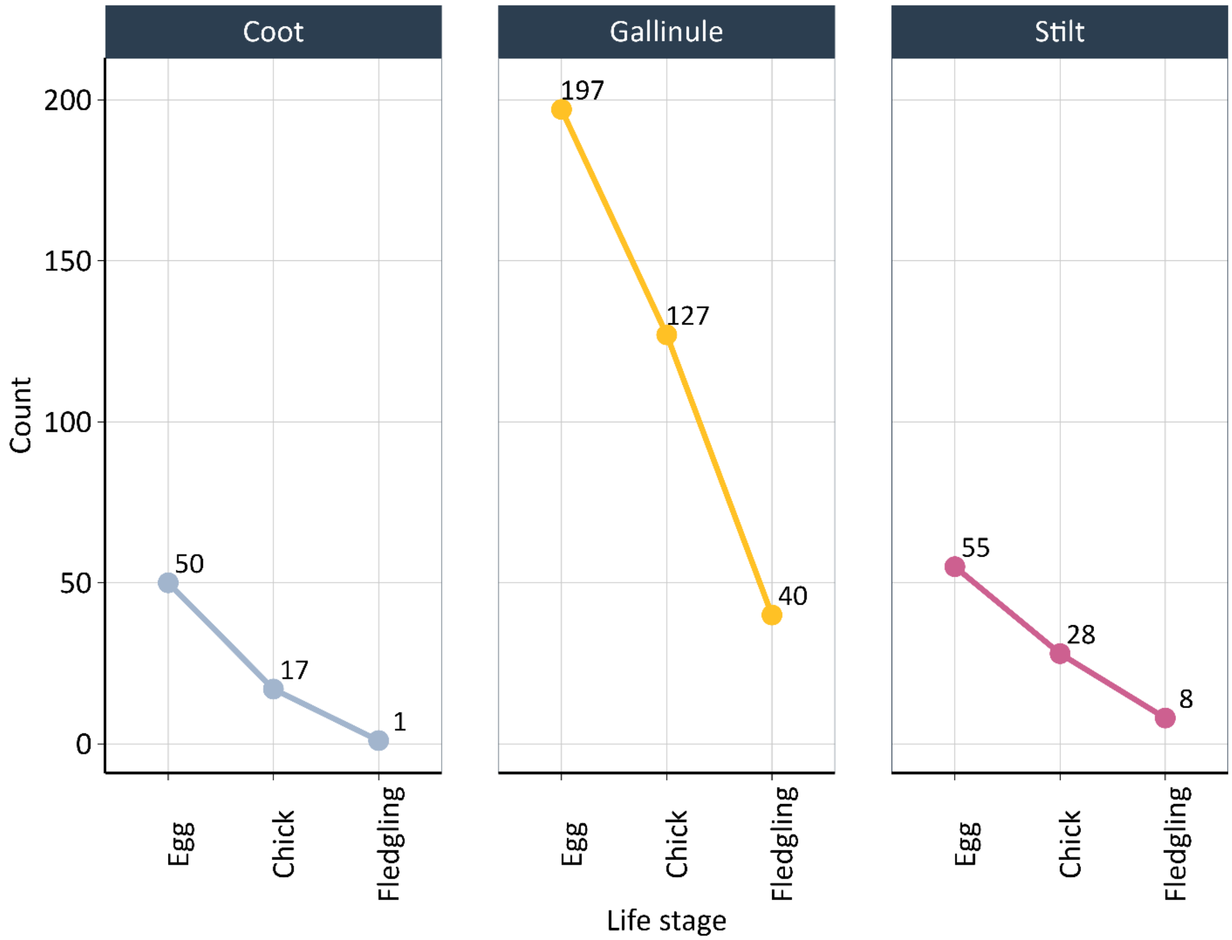

Figure 7. The number of eggs, chicks, and fledglings for coots, gallinules, and stilts in 2024 at Hāmākua Marsh State Wildlife Sanctuary, Oʻahu, Hawaiʻi.

Figure 8. A Hawaiian stilt chick carcass (ZL/ff:OA) found in Basin D; predated, most likely, by a Barn Owl (*Tyto alba*). The predator consumed the brain, organs, thighs, and breasts.

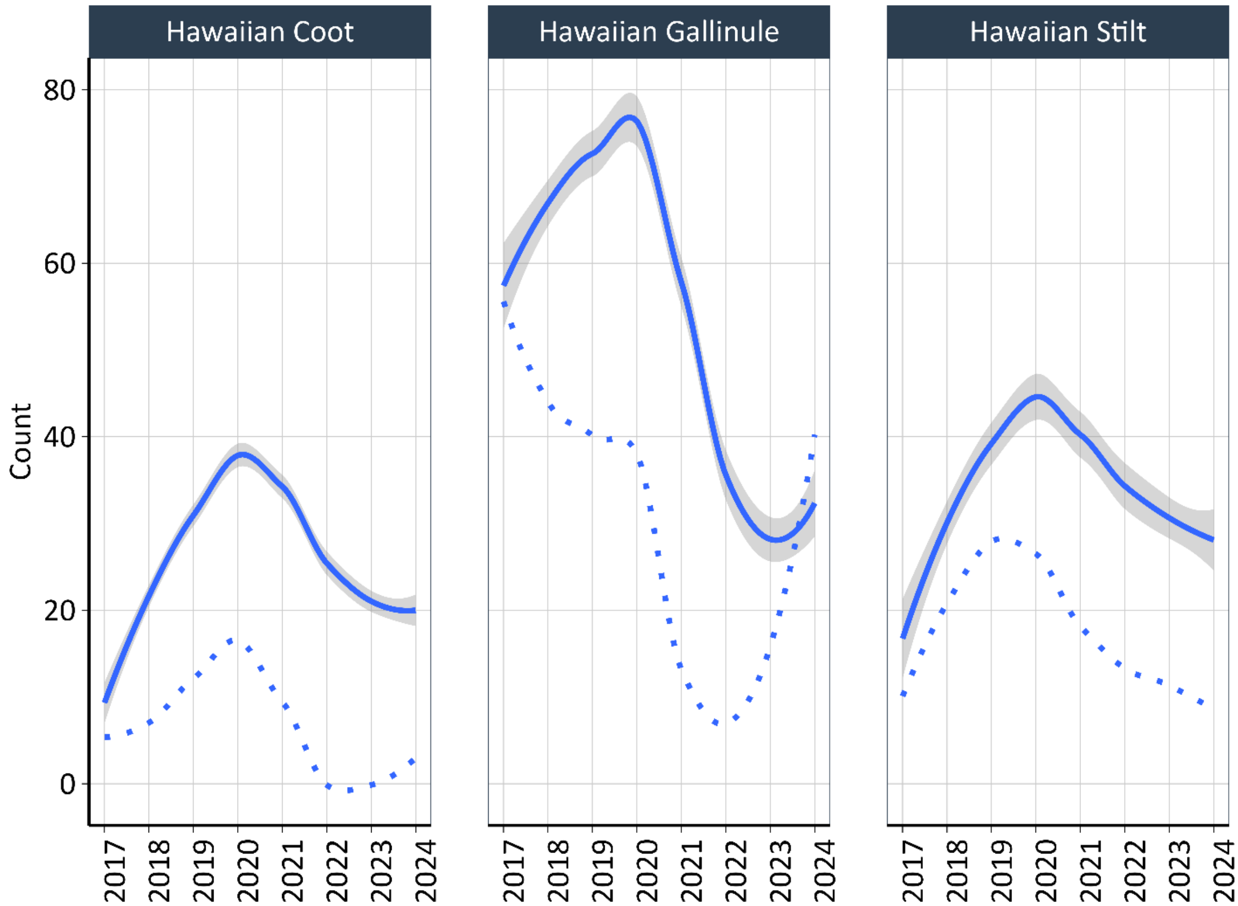

Figure 9. Average abundances for coots, gallinules, and stilts from 2017 through 2024 at Hāmākua Marsh State Wildlife Sanctuary, O‘ahu, Hawai‘i. Gray-shaded areas are 95% confidence intervals. The dotted line represents fledgling counts for each year.

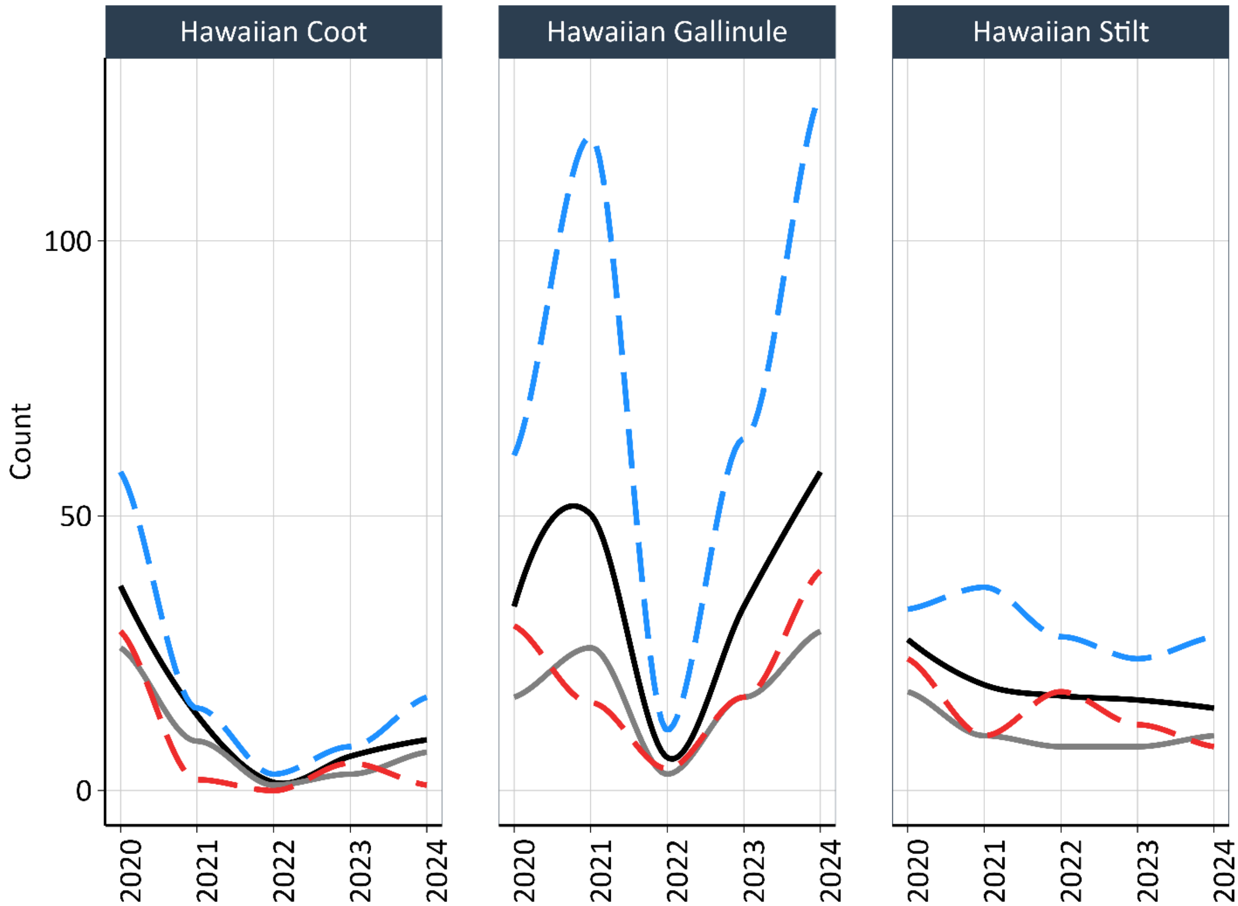

Figure 10. The counts of Hawaiian Coot, Hawaiian Gallinule, and Hawaiian Stilt nests (black solid), broods (gray solid), chicks (blue dash), and fledglings (red dash) from 2020–2024 at Hāmākua Marsh State Wildlife Sanctuary, O‘ahu, Hawai‘i.

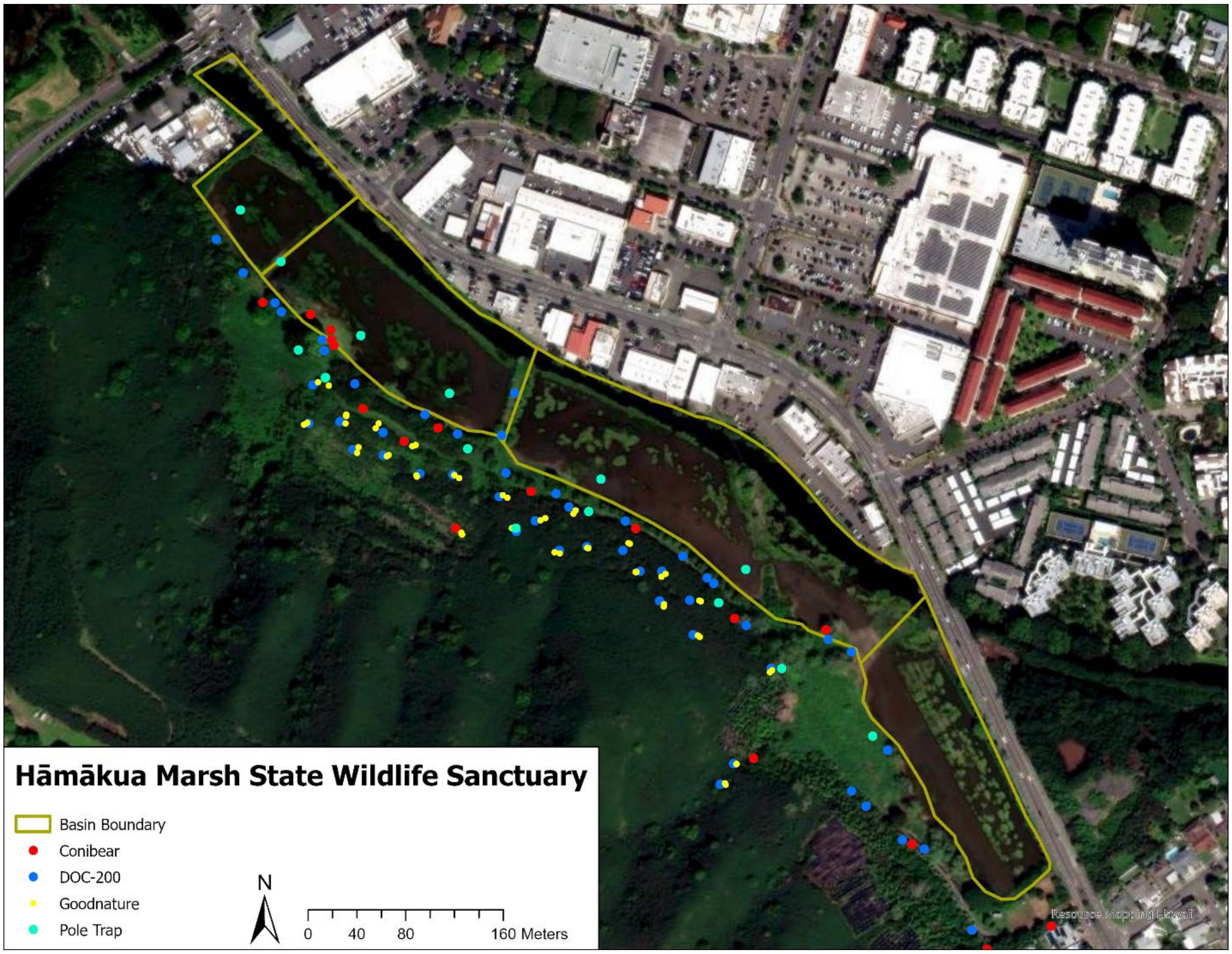

Figure 11. Map of trap distribution for DOC-200, conibear, Goodnature A18, and pole traps at Hāmākua Marsh State Wildlife Sanctuary, O‘ahu, Hawai‘i in 2024.

Table 1. Habitat manipulation operations and techniques used within the wetlands at Hāmākua Marsh Wildlife Sanctuary, Kailua, Hawai'i, USA from 2003–2024.

Year	Habitat manipulation
2003	Woody vegetation removed (i.e., mangrove)
2004	Woody vegetation removed (i.e., mangrove); tilling
2005	Limited tilling
2006	Tilling post-breeding 2005
2007	No tilling
2008	No tilling
2009	Increased vegetation removal; tilling post-breeding 2008
2010	Tilling post-breeding 2009
2011	No tilling
2012	Tilling post-breeding 2011
2013	No tilling
2014	Limited tilling
2015	Limited tilling
2016	No tilling
2017	Basin A was completely mowed and tilled; Basin B perimeters were tilled, interior left alone; Basin C interior was tilled leaving perimeters with buffer vegetation; Basin D was partially mowed and tilled in the interior.
2018	All Basins were mowed; Basin D was tilled.
2019	Half of Basins A and B were disked in January; Half of Basin A and all of Basins B, C, and D were disked in August; Half of Basin A and all of Basins B, C, and D were disked in October; but avoided disking center pickleweed islands in B and BolMar in Basin C.
2020	In early February, half of Basin A including the perimeter, the perimeter of Basin B, all of Basin C (minus the BolMar), and the perimeter of Basin D were disked to control mostly *B. maritima*. In late July, the untreated half of Basin A was cut and disked leaving patches and islands of taller *B. maritima*, the perimeter of Basin B was cut and disked leaving islands of *B. maritima* in the middle of the basin; all of Basin C was cut and disked leaving patches of BolMar, and Basin D was cut and disked leaving patches of BolMar. All cutting and disking in July focused on thinning the *B. maritima*. In late September, half of Basin A was tilled, a portion of Basin B between Basin A and the archeological site wall, and portions of Basin C. The BolMar in Basin C was mowed using the cutter attachment, and then those areas were manipulated using the tilling attachment.
2021	In January, half of Basin A (drier side) and *B. maritima* patches in Basin B, C, and D were disked with the Marsh Master. In September, half of Basin A (drier side) and all of Basin C and D were disked with the Marsh Master. In October, half of Basin A (drier side), the perimeter of Basin B, and half of Basin C (wetter side) and D (drier side) were disked with the Marsh Master. In December, half of Basin A (drier side), the perimeter of Basin B, all of Basin C, and half of Basin D (drier side) were disked with the Marsh Master.
2022	In October, half of Basin A (drier side), the perimeter of Basin B, and all of Basin C and D were disked with the Marsh Master. In November, half of Basin A (drier side), the perimeter of Basin B, half of Basin C (drier side), and half of Basin D (drier side) were disked with the Marsh Master.
2023	In mid-September, half of Basin A (drier side), the perimeter of Basin B, and all of Basin C and D were mowed with the Marsh Master MM-2XL. In early December, half of Basin A (drier side), the perimeter of Basin B, half of Basin C (drier side), and half of Basin D (drier side) were disked with the Marsh Master MM-2XL.
2024	In November, the pickleweed in Basin A was trimmed using a line trimmer. The edges of Basins A, B, C, and D were mulched using the skid steer and mulching attachment.

Table 2. The number of observed chicks, broods, fledglings, percent fledging success, and fledglings per brood for Hawaiian Coot, Hawaiian Gallinule, and Hawaiian Stilt from 2005–2024 at Hāmākua Marsh State Wildlife Sanctuary, Kailua, Hawaiʻi, USA.

	Coot				Gallinule				Stilt			
Year	# chicks (broods)	# fledglings	fledging success	fledglings per brood	# chicks (broods)	# fledglings	fledging success	fledglings per brood	# chicks (broods)	# fledglings	fledging success	fledglings per brood
2005	—	1	—	—	—	13	—	—	—	1	—	—
2006	—	0	—	—	—	50	—	—	19 (9)	17	89%	1.9
2007	2	1	50%	—	41	36	88%	—	16	13	81%	—
2008	—	5	—	—	35	33	94%	—	13	10	77%	—
2009	5	4	80%	—	52	50	96%	—	16	16	100%	—
2010	11	10	91%	—	56	44	79%	—	9	6	67%	—
2011	14	9	64%	—	33	30	91%	—	4	2	50%	—
2012	13	8	62%	—	31	20	65%	—	5	4	80%	—
2013	6	2	33%	—	43	25	58%	—	15	13	87%	—
2014	8	6	75%	—	95	77	81%	—	34	7	21%	—
2015	12	8	67%	—	62	42	68%	—	10	7	70%	—
2016	—	8	—	—	43	36	84%	—	42	32	76%	—
2017	11	6	55%	—	78	67	86%	—	12	9	75%	—
2018	13	7	54%	—	36	16	44%	—	16	7	44%	—
2019	13 (5)	3	23%	0.6	98 (27)	60	61%	2.2	27 (14)	20	74%	1.4
2020*	58 (26)	29	62%	1.1	61 (17)	30	49%	1.8	33 (18)	24	73%	1.3
2021*	15 (9)	2	13%	0.2	119 (26)	16	13%	0.6	37 (10)	10	27%	1.0
2022*	3 (1)	0	0%	0.0	11 (3)	4	36%	1.3	28 (8)	18	64%	2.3
2023*	8 (3)	5	63%	1.7	64 (17)	17	27%	1.0	24 (8)	12	50%	3.0
2024*	17 (7)	1	6%	0.1	127 (29)	40	31%	1.4	28 (10)	8	29%	0.8
Total	**209 (51)**	**115**	**55%**	**0.8**	**1085 (119)**	**706**	**65%**	**1.4**	**388 (77)**	**240**	**62%**	**1.4**

*Chick # determined through nest cameras.

Table 3. Summary of coot, gallinule, and stilt nest parameters (%HS = % hatching success) and nest failures. We collected data at Hāmākua Marsh, Kailua, Hawai‘i, USA, as determined by passive infrared cameras and manual nest surveys in 2024.

		Coot (*n*=14)	Gallinule (*n*=40)	Stilt (*n*=14)	Total (*n*=68)[a]
Camera		**8**	**33**	**12**	**53**
Nest parameters					
	Hatched (%HS)	3 (38)	24[b] (73)	9 (75)	36
	Clutch size	4.5	5.0	3.8	
Nest failures					
Predator	Small Indian Mongoose (*Urva auropunctata*)		1		1
	Black Rat (*Rattus rattus*)	1			1
	Hawaiian Coot (*Fulica alai*)		1		1
	Hawaiian Stilt (*Himantopus mexicanus knudseni*)			1	1
	Unknown		2		2
Other failure	Abandoned	4	1	2	7
	Flooded		4		6
No camera		**6**	**7**	**2**	**15**
Nest parameters					
	Hatched (%HS)	4[c] (67)	5[c] (71)	1 (50)	10
Nest failures					
Predator	Unknown		2		2
Other failure	Flooded			1	1
	Unknown	1			1
Unknown		1			1

[a]Sum of independent hatching and nest failure events.
[b]A Feral Cat (*Felis catus*) predates on three chicks and depredates two eggs in one nest, and a Barn Owl (*Tyto alba*) predates two chicks after they hatched in one nest.
[c]Two coot nests were found based on observing recently hatched chicks, and four gallinule nests were identified from observing recently hatched chicks.

Table 4. Reproductive metrics for coot (HACO; *n* = 14), gallinule (HAGA; *n* = 40), and stilt (HAST; *n* = 14) in Hāmākua Marsh, Kailua, Hawai‘i, USA, 2024. Nest success is the proportion of nests that produced ≥1 chick, fledging success is the proportion of broods that produced ≥1 fledgling, and overall reproductive success is the proportion of nests that produced ≥1 fledgling.

	Nest Success			Fledging Success			Overall Reproductive Success		
Year	HACO	HAGA	HAST	HACO	HAGA	HAST	HACO	HAGA	HAST
2020	71%	65%	51%	73%	88%	72%	53%	58%	37%
2021[a]	60%	71%	50%	13%	48%	27%	7%	30%	15%
2022[a]	50%	50%	50%	0%	67%	88%	0%	33%	47%
2023[a]	33%	50%	36%	100%	59%	88%	33%	29%	32%
2024[a]	50%	73%	83%	14%	66%	50%	7%	48%	36%

[a] Based on intensive monitoring, not an estimation.

Table 5. Predators captured by month at Hāmākua Marsh, Kailua, Hawai‘i, USA, 2024.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mongoose	4	5	3	3	4	1	4	3	5	4	2	13	51
Cat	0	2	0	3	2	1	0	2	1	1	1	2	15
Rat	3	4	9	11	9	5	3	6	4	6	6	7	73