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Hāmākua Marsh State Wildlife Sanctuary

Waterbird Report, 2023

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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, Hawai'i. Hāmākua Marsh is a seasonally brackish wetland on the windward side of the Ko'olau Range on the island of O'ahu.

Hāmākua Marsh has been identified by the U.S. Fish and Wildlife Service 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 with the goal of creating 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 is comprised of 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 offer different proportions of open water to vegetation or mudflat. The wetland is fed from rainfall and runoff from the adjacent 68-acre Pu'u o 'Ehu 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 2023 included mowing once in mid-September and disking once in early-December using a Marsh Master MM-2XL equipped with the cutter and disking attachments, respectively. This was the second time the habitat was altered twice; the previous three consecutive years the habitat was altered three times (Table 1). Previously, the interior wetland area was manipulated once during the year, yet in 2019–2021 the habitat was selectively manipulated on three separate occasions while avoiding stilt nesting season (March–August); in 2022 and 2023 the habitat was manipulated twice.

Mechanical manipulation was incorporated to minimize the pickleweed (*Batis maritima*) and to promote growth of the naturally occurring native seed bank, leaving islands of pickleweed habitat for nesting. Basin A was managed 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 managed 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 managed 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 diametrically 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. When planning habitat management for waterbirds in wetlands those manipulations for optimizing foraging may include disking and tilling, but for areas that nesting is encouraged pickleweed needs manipulation no more than once annually. Foraging for coots, gallinules, and stilts takes place in more open habitat 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). In another study, it was posited that aquatic invertebrate mass and diversity was greatest 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 2023, water levels ranged from 0–20.1, 11.4–24.6, 0–18.0, and 0–15.6 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 and ranged from 5–20, 1–3, 5–35, and 4–24 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. A census technique was used to count all waterbirds present using the direct count method. Waterbird surveys were conducted using consistent observation lines to maintain consistency amongst different 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 of the endangered wetland birds 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 was recorded as ranging 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 2005–2023, endangered waterbird fledging success was measured using the formula: (# of observed fledglings/# of observed chicks) x 100 = % fledging success. Fledglings and chicks were mapped 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 all observed and 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 used for comparison from other sites. The older method of calculating fledging success will be used as well, mostly to continue comparisons from previous years.

2. Results

Surveys.—A total of 50 surveys were conducted at Hāmākua Marsh in 2023. Mean abundances (range) for coots were 21.4 individuals (14–45), gallinules were 29.0 individuals (24–65), and stilts were 32.6 (12–81) 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 3.6 individuals.

Habitat Use.—Habitat utilization differed by species. The Hawaiian Coot was found most often in stream with 41.1% of the observations; the Hawaiian Gallinule was found most often in vegetation with 43.2% of the observations; and the Hawaiian Stilt was found in most often in 0–3" water with 47.0% of the observations (Figure 4). Coots utilized deeper water habitat, gallinules used vegetation, and stilts used shallow water and mudflat.

Fledging Success.—Fledging success in Hāmākua Marsh State Wildlife Sanctuary from 2005 to 2023 ranged from 0–91%, 13–96%, and 21–100% for coots, gallinules, and stilts, respectively. For 2023 coots, gallinules, and stilts had an overall fledging success rate of 63%, 27%, and 50%, respectively (Table 2). Fledging success rate in 2023 for gallinules and stilts was below the pooled averages (66% and 67%, respectively); and above average for coots (53%). Coot fledging recruitment was 5 fledglings which was an average recruitment for coots. The annual average recruitment for coots was 6.0 fledglings per year. Gallinule fledging recruitment was 17 fledglings which is below the annual average recruitment of 35.1 fledglings per year. Stilt fledging recruitment was 12 fledglings which is nearly the annual average recruitment of 12.6 fledglings per year.

3. Recommendations

Chick survival estimates are labor intensive and require daily observations of marked chicks. Alternatively, in 2024 Lukacs's brood survival estimates will be modeled to achieve a brood survival statistic to inform the Wildlife Biologist of fledgling survival more accurately.

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, a team of 3−7 observers walked meandering transects with the goal of locating 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 non-stilt nesting season focus was made on searching coot and gallinule nest habitat.

Waterbird nests were monitored from January through December 2023. Nest success was monitored using SPYPOINT Solar Dark (GG Telecom, Quebec, Canada) passive infrared cameras (trigger speed: 0.07s) 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 and were removed either immediately after a nest was confirmed failed or after a nest was confirmed successful (coot and gallinule nest cameras remained for 14 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-three nest surveys were conducted from January through December 2023. Nests were found in March–August for Hawaiian Coot, January–July for Hawaiian Gallinule, and May through June for Hawaiian Stilt. During the period of January through December 2023, 9 coot, 36 gallinule, and 22 stilt nests were observed (Figure 6). Out of 67 nests observed, Basin B contained the most nests (*n* = 29), then Basin A (*n* = 18), Basin C (*n* = 15), and Basin D (*n* = 5). Coot nests were found most often in Basin B (56%); gallinule nests were found most often in Basin A and B (67%); and stilt nests were most often found in Basin B (55%; Figure 6).

Nests observed peaked for coot and gallinule in March, and stilt nests observed peaked in May; and from September–December no nests were found for all species except two gallinule nests (December [2]; Figure 6 [see Figure 7 for nest abundances by Basin]).

<u>Overall Nest Outcomes</u>
Out of 67 nests discovered, 42% (*n* = 28) produced at least one chick, 24% (n = 16) failed due to predation or partial predation, 10% (*n* = 7) failed due to flooding, 18% (*n* = 12) failed due to abandonment, 3% (*n* = 2) failed for unknown reasons, and 3% (*n* = 2) had unknown fates (Table 3).

<u>Outcomes of Nests Monitored with Cameras</u>
Out of 67 nests, 57 (85%) had a camera placed on them. Cameras were placed on 56%, 89%, and 91% of coot (*n* = 5), gallinule (*n* = 32), and stilt (*n* = 20) nests, respectively. Of the 57 nests with cameras, 42% (*n* = 24) produced at least one chick, 28% (n = 16) failed due to predation or partial predation, 16% (*n* = 9) failed due to abandonment, 12% (*n* = 7) failed due to flooding and 0% (*n* = 1) failed for unknown reasons (Table 3).

Reproductive Success.—We observed 3 coot, 17 gallinule, and 8 stilt broods; and 3 coot, 10 gallinule, and 7 stilt broods produced ≥1 fledgling (Table 4). The number of broods observed per nest were 0.5, 0.5, and 0.5 broods for coots, gallinules, and stilts, respectively. The number of fledglings per brood was 1.7, 1.0, and 3.0 fledglings for coots, gallinules, and stilts, respectively. The number of fledglings per nest was 0.6, 0.5, and 1.1 fledglings for coots, gallinules, and stilts, respectively.

3. Discussion

Nest Monitoring.—Coot nesting success was reported to be high at 80% and the average clutch size was 5 eggs per nest (range: 1–10 eggs per nest; Pratt and Brisbin, 2002). Our study reported below average nesting success at 33%.

Gallinule nesting success, as reported by van Rees et al. (2018), averaged 66% when combining data from five separate studies (range: 42–77%). The average clutch size was 5.1 eggs per nest (range: 4.2–6.3 eggs per nest; van Rees et al., 2018). Our study reported below average nesting success for gallinules at 50%.

Stilt nesting success for Hāmākua Marsh, Kawainui Marsh, Honouliuli wetland unit, Waiawa wetland unit, and James Campbell National Wildlife Refuge in study years 2018 and 2019 was 63% for those nests that were monitored with a camera (Price, 2020). In 2023, Hāmākua Marsh had a stilt nesting success of 36%. The nesting success for Hāmākua Marsh was below average when compared with other Oʻahu wetlands and across two separate nesting seasons. In 2018 and 2019, Hāmākua Marsh had a stilt nesting success of 47% and 68%, respectively (Price, 2020). Comparing stilt nesting success in 2023 to nesting seasons 2018 and 2019 (nesting success 58% combined), nesting success was below average.

Outcomes of Nests Monitored with Cameras
Of nest failures, 27 of 33 (82%) nests failed due to predators or abandonment. Mongoose were responsible for 1, 3, and 10 failed coot, gallinule, and stilt nests. Abandoned nests were incubated to full-term and contained inviable or undeveloped eggs in 3 and 7 coot and gallinule nests; one gallinule nest was abandoned due to predator presence and three stilt nests were abandoned for unknown reasons. In 2023, mongoose predation was highest ever recorded and undeveloped eggs are a concern (Table 3).

Reproductive Success.—As reported in the Kahuku Wind Power Habitat Conservation Plan, coots, gallinules, and stilts had 0.9, 1.3, and 0.9 chicks per observed brood per other studies (SWCA, 2010). In 2023, at Hāmākua Marsh coots had 1.7 fledglings per brood, gallinules had 1.0 fledglings per brood, and stilts had 3.0 fledglings per brood. Fledglings per brood observed is average, below average, and above average for coots, gallinules, and stilt, respectively, compared with other studies.

4. Recommendations

Nest Monitoring.—Weekly surveys are needed to observe all the nests throughout the nesting season and continuing with weekly surveys is recommended. In 2024, 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, 85% of nests had a camera placed to monitor the nest fate, and 100% of all waterbird nests a fate could be determined due to frequent twice weekly nest checks. However, an additional 15% 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 visit 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 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.— One stilt or gallinule chick per brood was affixed with a radio transmitter (Holohil LB-2X), if the chick in the brood had perished another chick within the same brood was fitted with another transmitter if possible. Chicks were located daily to twice daily with a VHF telemetry receiver (Telonics TR-8 VHF Receiver; RA-23K VHF Antenna) until chick death or transmitter failure. Radio transmitters were re-glued weekly to ensure transmitter retention. Deceased stilt chicks with transmitters were necropsied to aid in determining the cause of death. Mortality was determined to be: predation, starvation, exposure, or unknown. All chicks of appropriate size, regardless of transmitter affixation, were banded with a USGS metal band and uniquely identifiable auxiliary band combination.

2. Results

Chick Monitoring.—In 2023, eight coot chicks hatched from an available 29 eggs (28%). Of the 8 chicks that hatched only one (13%) chick was marked with nail polish and one chick received a transmitter. A total of five chicks fledged from 3 separate broods (OA:BY [HC05-2023]; others unmarked from HC07-2023 and HC09-2023).

Sixty-four gallinule chicks hatched from an available 165 eggs (39%). Of the 64 chicks that hatched only 30 (47%) chicks were marked with nail polish. Eighteen chicks received a transmitter from 14 separate broods. A total of 17 chicks fledged from 10 separate broods. Fates were difficult to determine due to low tag retention rates. If a tag were found unattached from a chick, then the fate was unknown since the tags were being picked off by the parents within a 1–5 days and chicks were difficult to observe.

Twenty-four stilt chicks hatched from an available 81 eggs (30%). Of the 24 chicks that hatched 18 (75%) chicks survived to transmitter or banding size (typically 7−10d of age). Nine chicks received a transmitter from six separate broods. Of the 18 chicks closely monitored with bands and transmitters, 11 (61%) chicks survived to the fledgling stage.

HAST Chick Survival (Transmitters Equipped; *n* = 9)
Of the nine stilt chicks marked with a transmitter four (44%) chicks survived. Of the five stilt chick deaths, three (60%) could be attributed to possible predation, one from mongoose (20%), and one from emaciation/trauma (20%; USGS Necropsy Report 25918). In the confirmed mongoose predation, the transmitter with surrounding glue patch had mongoose teeth marks (Figure 10).

HAST Chick Survival (Plastic Leg Bands Only; *n* = 9)
Of the nine chicks monitored with bands only, seven (78%) chicks survived.

3. Discussion

Chick Monitoring.—Coot chick mortality was low at 38% (*n* = 3 dead chicks). Transmitter data was inconclusive.
Gallinule chick mortality was high at 73% (*n* = 47 dead chicks). Transmitter data was inconclusive.
Stilt chick mortality was high at 54% with all stilt chicks (*n* = 13 dead chicks) and similar when looking at the chicks outfitted with a transmitter (*n* = 5) at 56%. An average of 23.2d (10–50d) elapsed since hatch for stilt chicks that failed. Also, 24/7 video surveillance was used in the vicinity of the known mongoose predation event, but the predation event was not visible and likely took place underneath the pickleweed where the transmitter was recovered.

4. Recommendations

Chick Monitoring.—We will monitor chicks in 2024 through visual observations and projecting success using a brood survival model (Lukacs's). Careful observations in areas of known hatched nests will be observed for longer periods of time to aid in the observation of chicks within a brood through the fledgling stage.

d. Long-term Waterbird Population Analysis

1. Results

Survey.—A total of 310 waterbird surveys were conducted during 2017–2023 (*n*=25, *n*=44, *n*=45, *n*=49, *n*=50, *n*=47, *n*=50, respectively). The average coot abundance for those years were 14, 17, 30, 40, 35, 24, and 21 individuals; the average gallinule abundance was 69, 54, 72, 82, 57, 34, and 29 individuals; and the average stilt abundance was 20, 26, 40, 46, 41, 33, and 33 individuals, respectively (Figure 8).

2. Discussion

The populations of coots, gallinules, and stilts at Hāmākua Marsh increased from 2018–2020 and decreased in 2021–2023; coot, gallinule, and stilt populations decreased on average 19%, 49%, and 3% in 2023, respectively. The cause in the decrease of coot, gallinule, and stilt populations was unknown, but could have been due to emigration of waterbirds to nearby wetlands. This may have been spurred on by meeting habitat carrying capacities at Hāmākua Marsh even given the new habitat manipulation regimen.

3. Recommendations

We have experienced a decrease in population averages for coots, gallinules, and stilts in the last three years. All three species are below their pooled averages from 2017–2023, but gallinules are 2.8x lower than their peak. In 2024, focus will be on training and experience with backpack attachment of GPS transmitters on coots and gallinules. This experience is necessary to amend the Bird Banding Lab (BBL) permit for both gallinule and Hawaiian Duck to receive GPS transmitters attached with a backpack-style harness. 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

DOC-200 kill traps (*n* = 16) were deployed for 5706 trap days in 2023; and one conibear cat-kill trap was distributed along the road in the interior that paralleled the marsh. The DOC-200 and conibear traps were mounted inside housings to protect the trap mechanism from the elements and to eliminate incidental take of non-target species. The DOC-200 kill traps and conibear trap were baited weekly to monthly with dry cat food mixed with either salmon oil, shellfish oil, or crayfish oil. All traps were checked weekly and left opened always.

b. Results

DOFAW trapped 35 small Indian mongooses (*Urva auropunctata*), 45 rats (*Rattus* spp.), and 3 cats (*Felis catus*; Table 5).

c. Recommendations

Mongooses trapped in 2023 was well below the annual average mongoose take from 2007–2019 (127 mongooses). DOFAW changed trapping techniques from contracted live trapping efforts to in-house kill-trapping in June of 2020.

Despite the lower trapping success of mongooses from 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 will include Goodnature A18 Mongoose Multi-kill traps for 2024.

At Hāmākua Marsh mongoose control seems less necessary than at Pouhala Marsh. In 2021, at Hāmākua Marsh, 0 of 58 nests monitored by a camera were depredated by a mongoose. On one occasion a mongoose was captured on camera pipping a gallinule egg and the egg was removed by the attending gallinule, but this nest was successful. In contrast, Pouhala Marsh had 3 of 5 (60%) stilt nests, monitored by cameras, predated by mongooses. Interspecific and intraspecific competition is more of an issue for nest success at Hāmākua Marsh as 9 of 58 (16%) nests, monitored by cameras, were predated, or abandoned possibly due to the presence of coot, gallinule, or stilt.

V. Conclusions and Goals for 2024

Hāmākua Marsh provides adequate habitats for all endangered waterbirds present on Oʻahu. While Hāmākua boasts 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 increasing numbers of coots, gallinules, and stilts remains the greatest priority to managers of Hāmākua Marsh.

Waterbirds have many threats that impact 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 2024, we will continue nest monitoring with cameras to inform the Biologist on predator control efficacy. The Biologist will continue intensive monitoring and training for applying 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 for increasing predator control and conducting two mongoose control projects: one focused on a mongoose toxicant and the other on Goodnature A18 mongoose multi-kill traps with two bait types (placebo fish sausage from ACTA and the Meat Lovers Automatic Lure Pump from Goodnature).

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VII. Appendix

a. List of Figures and Tables

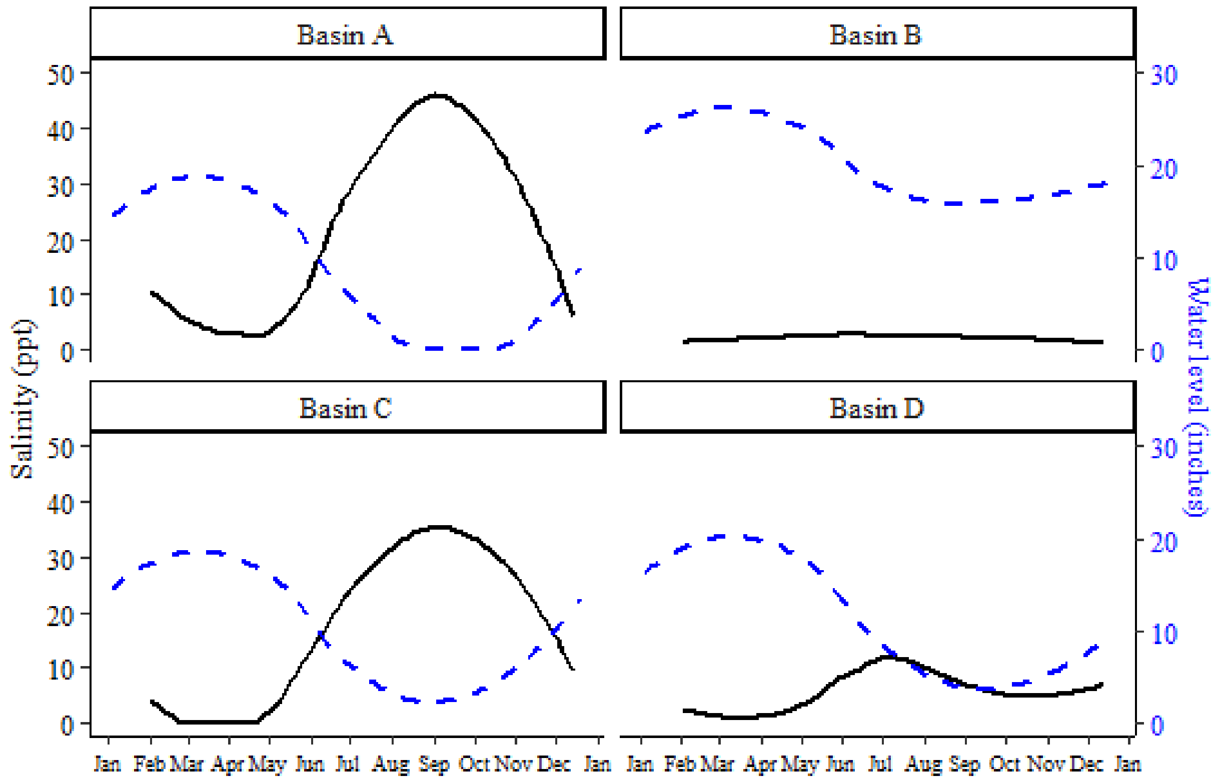

Figure 1. Water level and salinity in Basins A, B, C, and D in Hāmākua Marsh State Wildlife Sanctuary on O'ahu, Hawai'i as measured in 2021 (not measured consistently in 2022 or 2023). The blue dashed line is water level, and the red solid line is salinity.

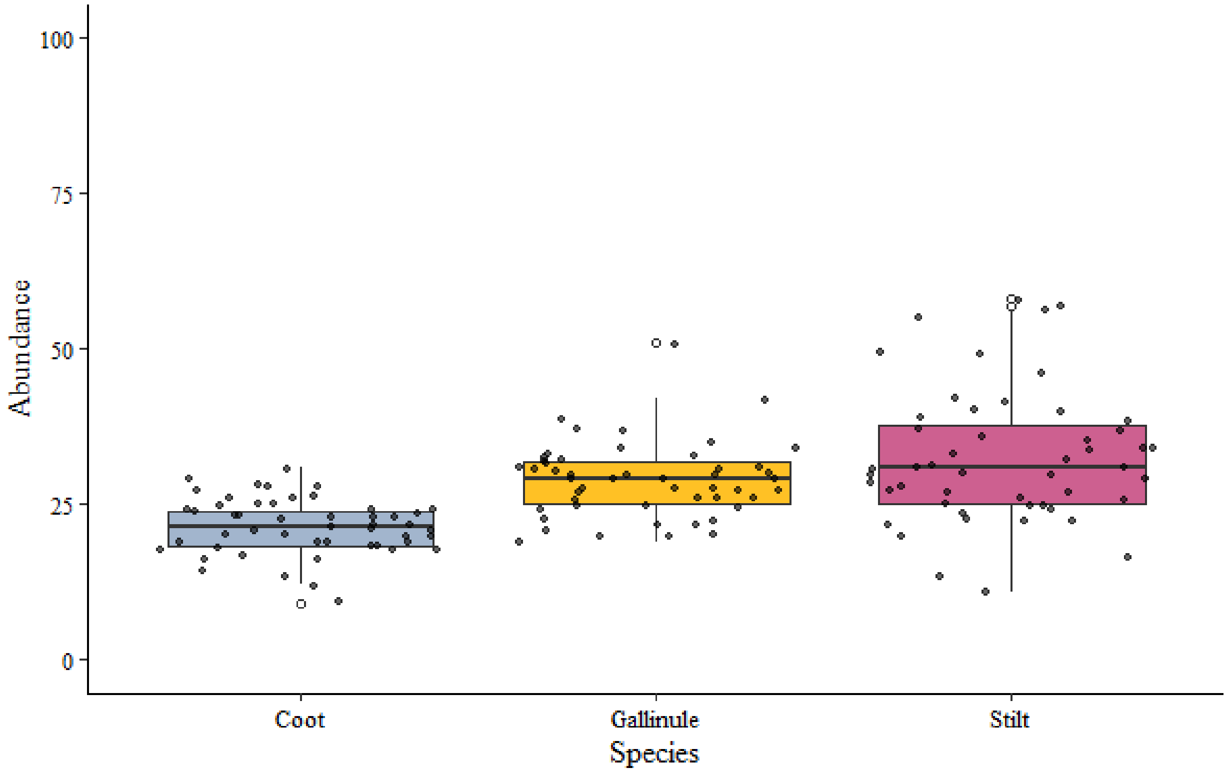

Figure 2. Boxplot displaying median values and interquartile ranges for coots, gallinules, and stilts in Hāmākua Marsh State Wildlife Sanctuary on Oʻahu, Hawaiʻi. Black points represent abundances for each individual survey (*n* = 50) in 2023. Open circles are outliers and whiskers represent minimum and maximum.

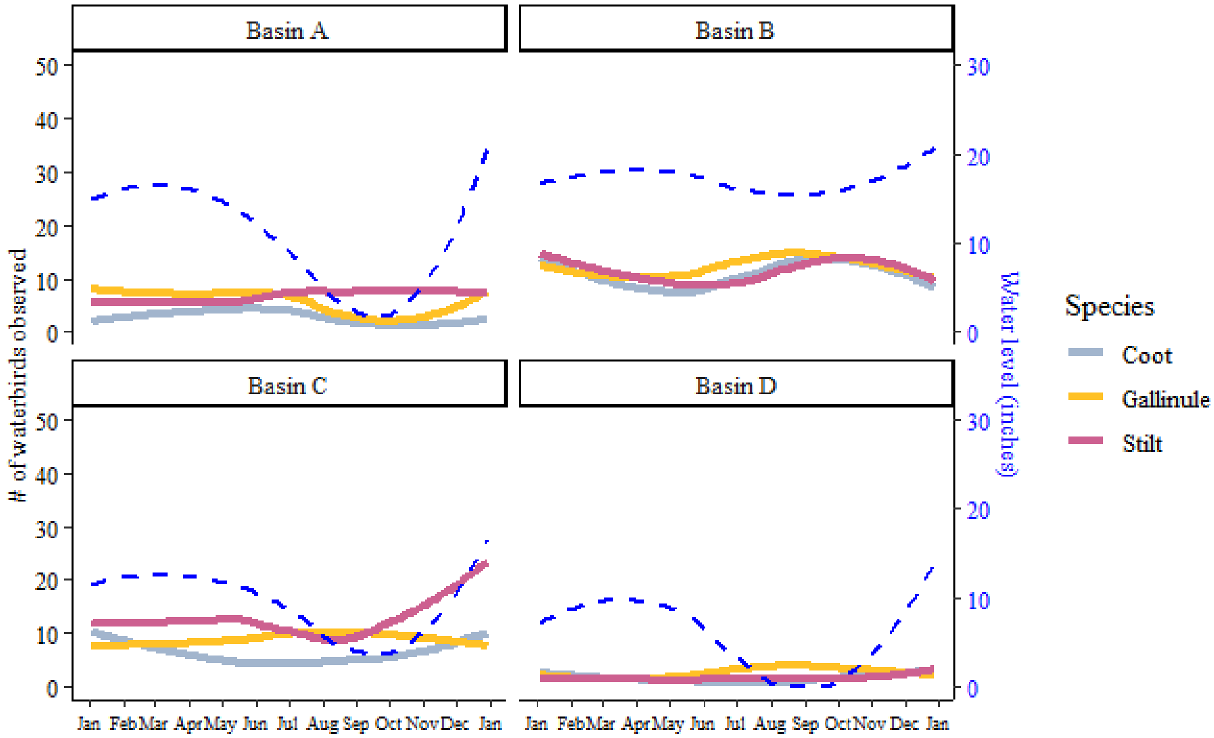

Figure 3. Waterbird abundance by species, basin, and month in Hāmākua Marsh State Wildlife Sanctuary on Oʻahu, Hawaiʻi in 2023. The blue dashed line is the water level in inches.

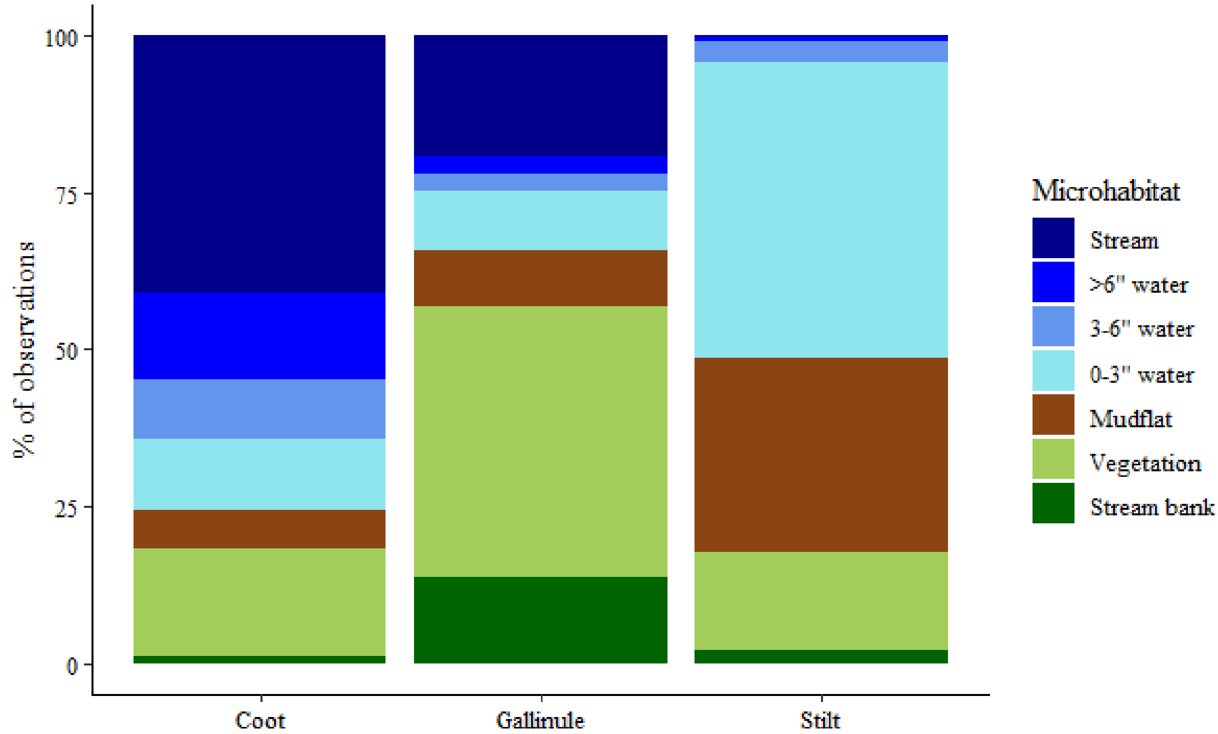

Figure 4. Percent of observations for coots, gallinules, and stilts in seven microhabitats found within Hāmākua Marsh State Wildlife Sanctuary on O‘ahu, Hawai‘i in 2023.

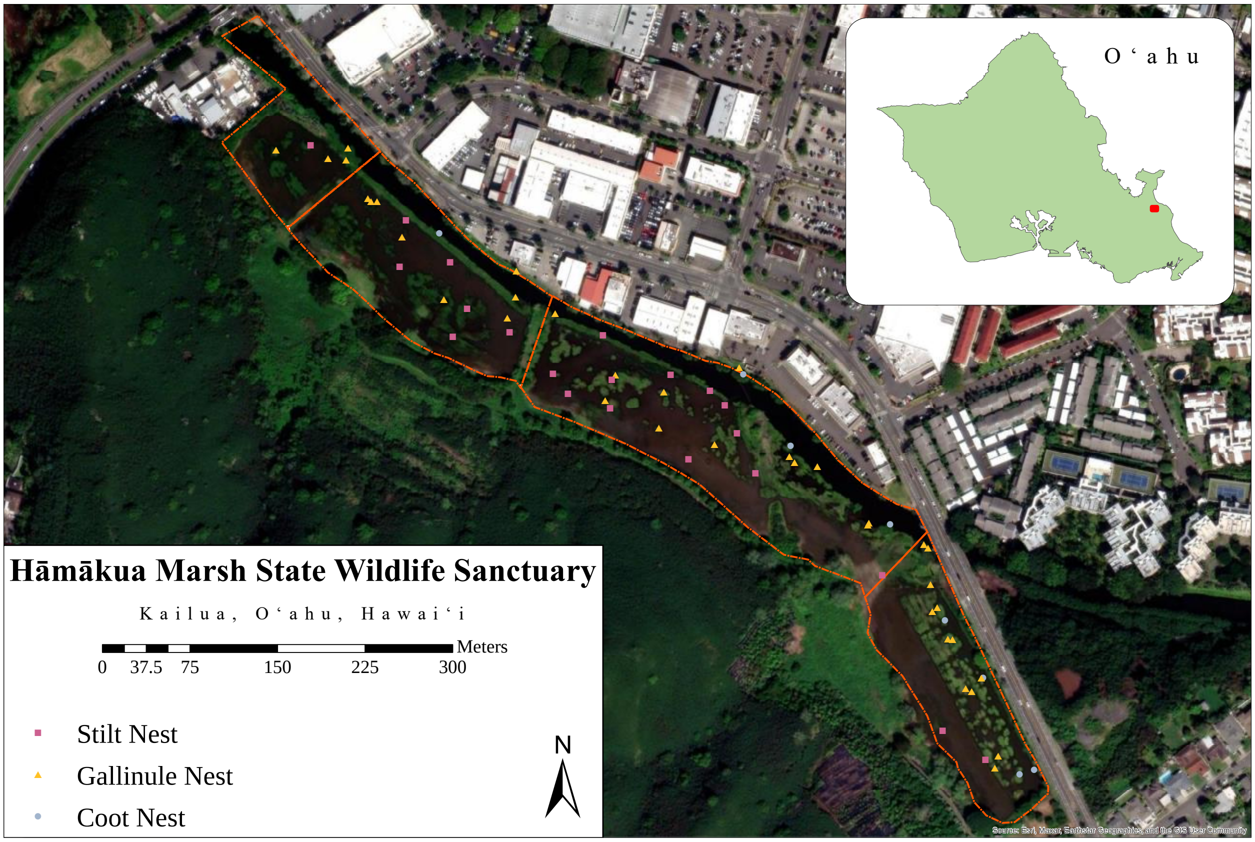

Figure 5. Nest distribution map for Hāmākua Marsh State Wildlife Sanctuary. Pictured are 9 coot (A-4, B-4, C-1, D-0), 36 gallinule (A-12, B-12, C-8, D-4), and 22 stilt (A-3, B-12, C-6, D-1) nests observed in 2023. Nest surveys were conducted weekly and biweekly.

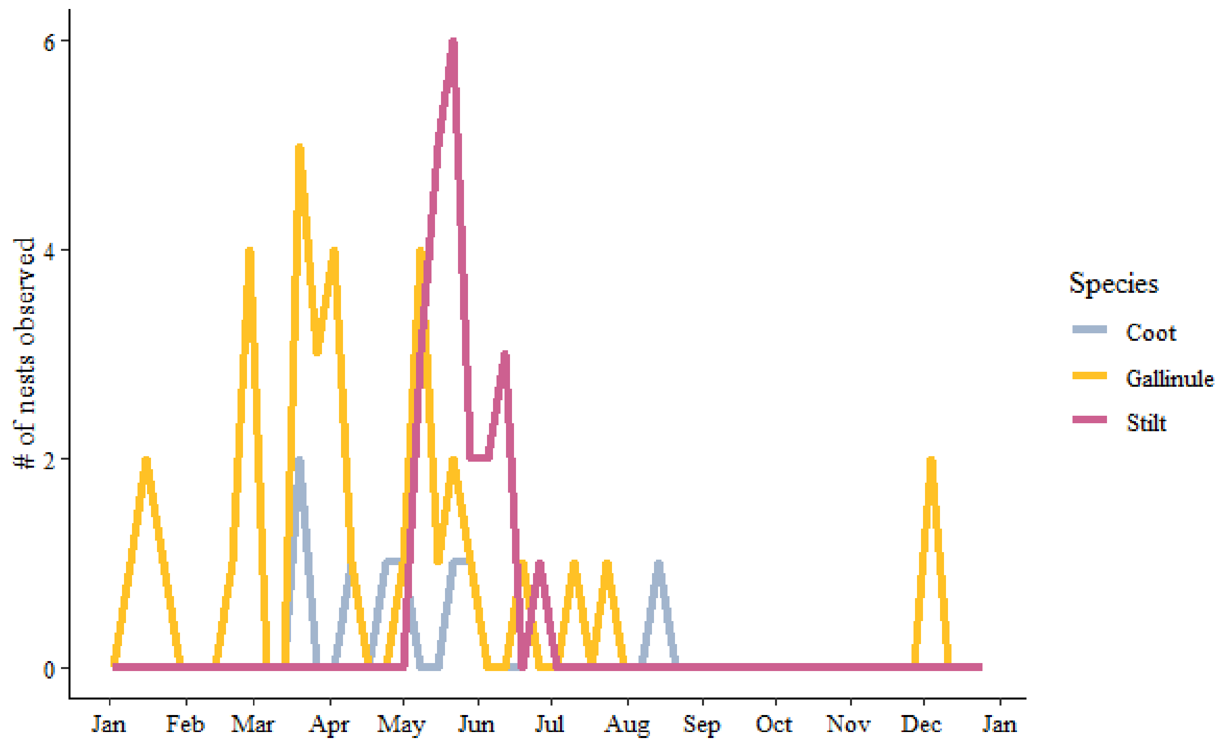

Figure 6. Number of nests found by nest survey. One nest survey was conducted weekly from January–August and December, and biweekly from September–November 2023.

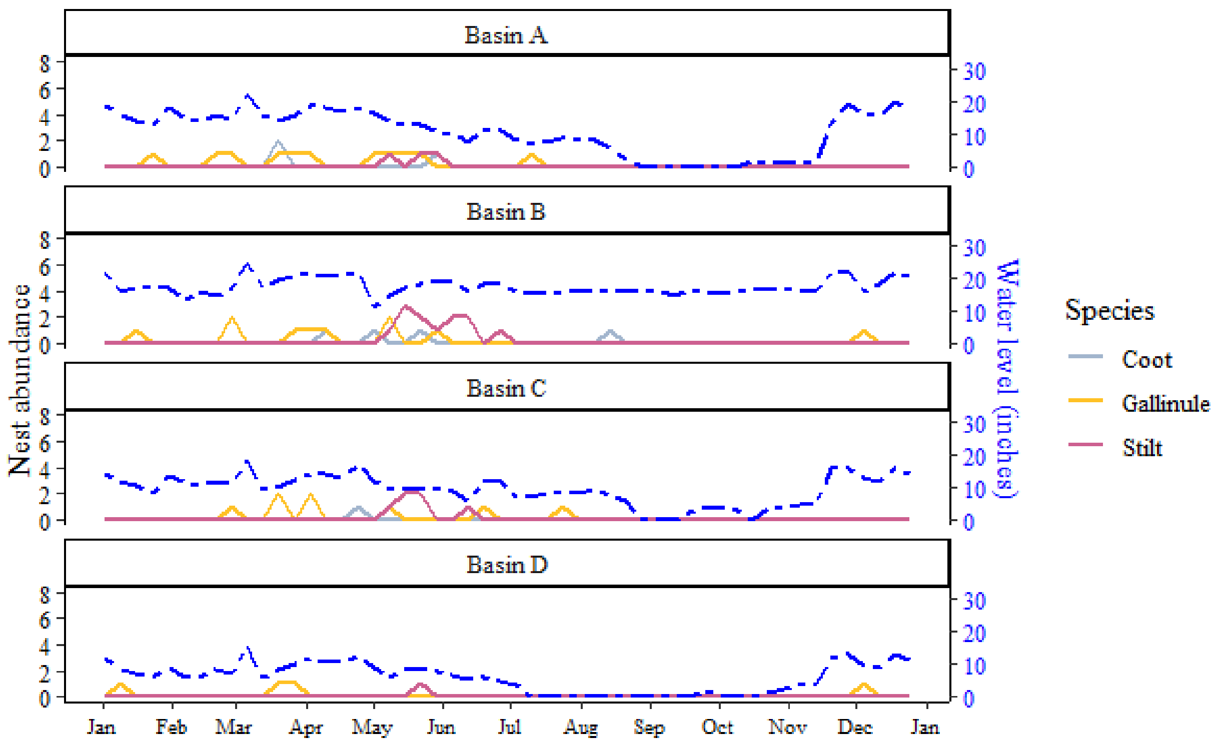

Figure 7. Nest observations and average water level by species and basin from January–December 2023 at Hāmākua Marsh State Wildlife Sanctuary, O‘ahu, Hawai‘i. The blue dashed line is the water level (inches) during each survey.

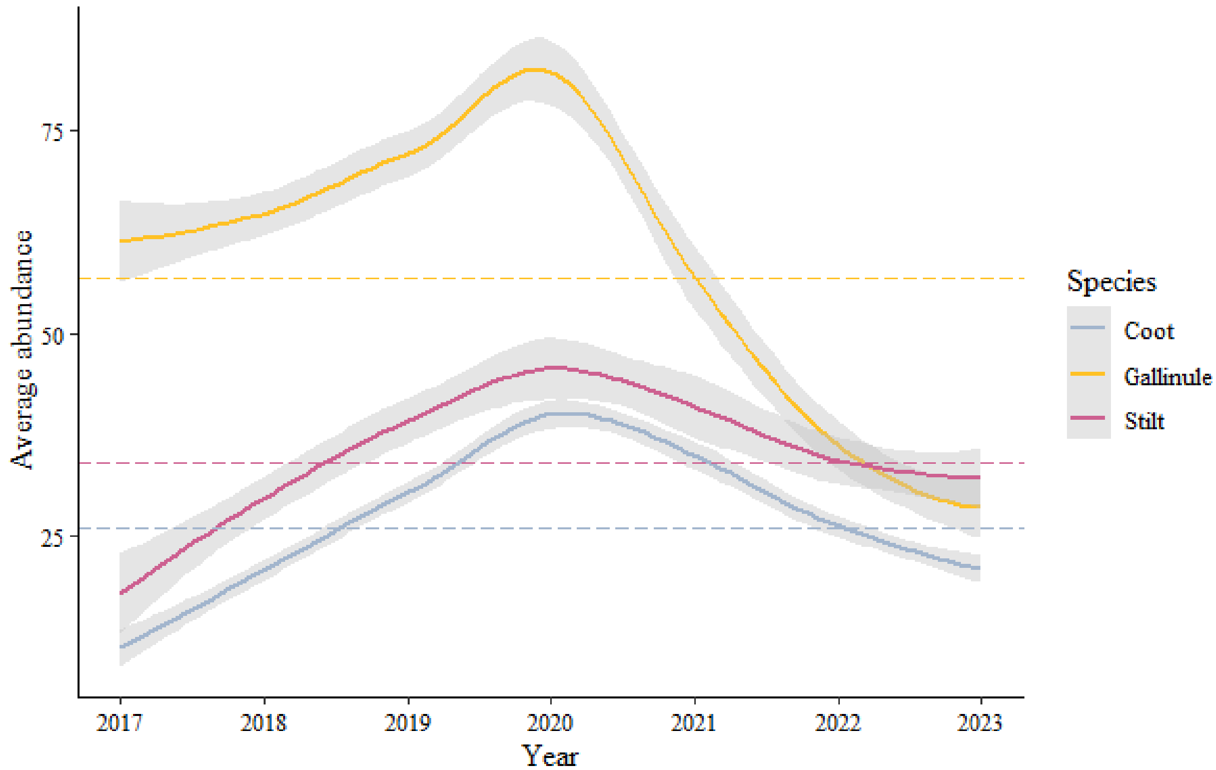

Figure 8. Average abundances for coots, gallinules, and stilts from 2017 through 2023 at Hāmākua Marsh State Wildlife Sanctuary, Oʻahu, Hawaiʻi. Gray shaded areas are 95% confidence intervals, horizontal dashes (color coded by species) represent the pooled averages for each species over the span 2017–2023.

Figure 9. Map of trap distribution for DOC-200 and conibear traps at Hāmākua Marsh, Oʻahu, Hawaiʻi.

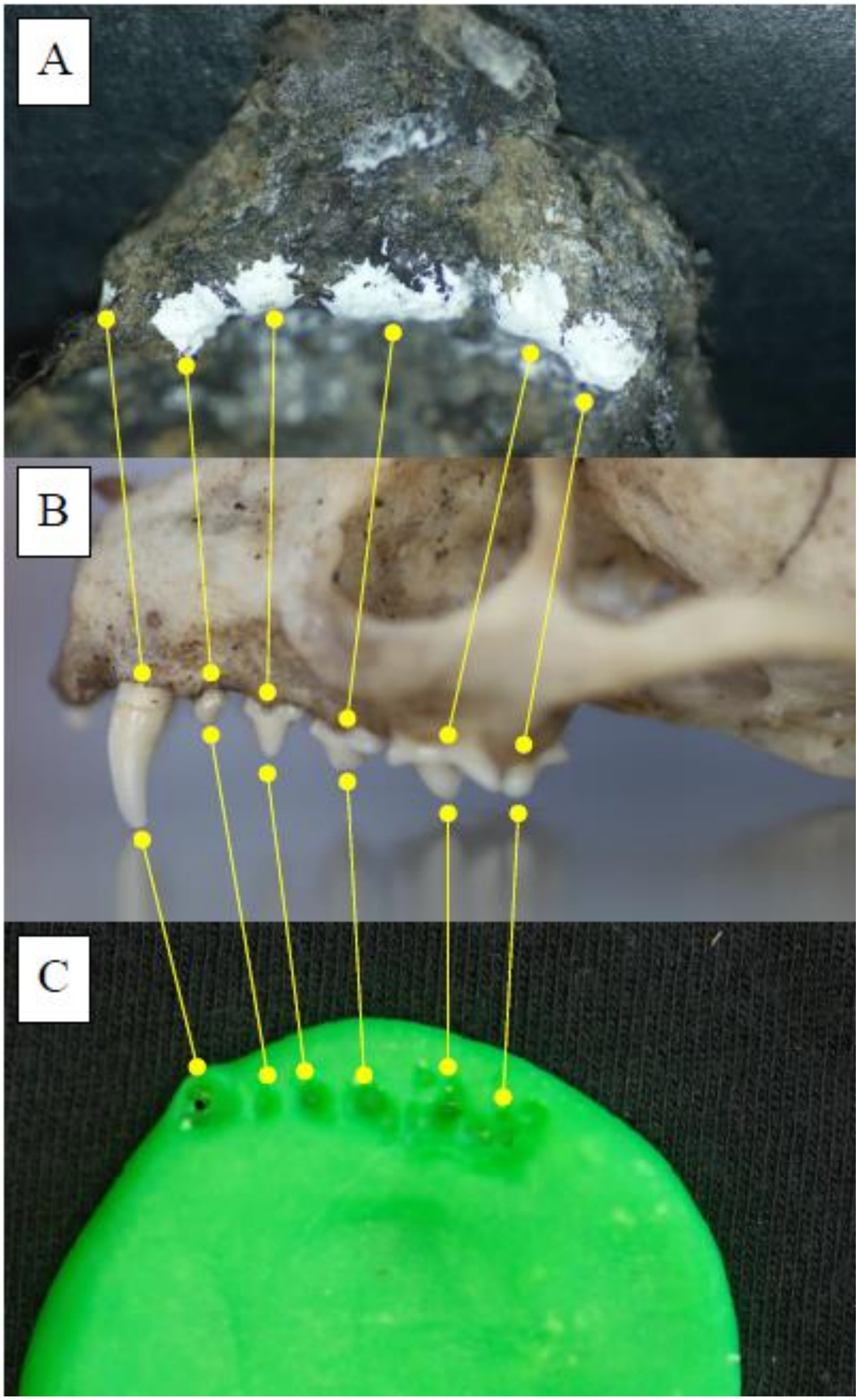

Figure 10. (A) Glue patch surrounding radio-tag with mongoose toothmarks from the left side of the skull, highlighted in white for emphasis; (B) corresponding yellow lines matching the dentition pattern on the left side of a mongoose skull; (C) mongoose tooth impression matched to the glue patch of the transmitter.

Table 1. Habitat manipulation operations and techniques used within the wetlands at Hāmākua Marsh Wildlife Sanctuary, Kailua, Hawaiʻi, USA from 2003–2023.

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 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 if *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 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), 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), 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), 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), 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), 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), 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.

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 2005–2023 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
Total	**191 (44)**	**114**	**53%**	**0.7**	**958 (90)**	**666**	**66%**	**1.4**	**348 (67)**	**240**	**67%**	**1.8**

*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 2023.

		Coot (*n*=9)	Gallinule (*n*=36)	Stilt (*n*=22)	Total (*n*=67)[a]
Camera		**5**	**32**	**20**	**57**
Nest parameters					
	Hatched (%HS)	1 (20)	16 (50)	7 (35)	24
	Clutch size	3.6	4.9	4.0	
Nest failures					
Predator	Small Indian Mongoose (*Urva auropunctata*)	1	3	9	13
	Hawaiian Coot (*Fulica alai*)			1[b]	1
	Unknown			1	1
Other failure	Abandoned	3[c]	7[d]	2	12
	Flooded		6		6
No camera		**4**	**4**	**2**	**10**
Nest parameters					
	Hatched (%HS)	2(50)	2(50)	0(0)	4
Nest failures					
Other failure	Abandoned	1	2	1[e]	4
Unknown		1		1	2

[a]Sum of independent hatching and nest failure events.
[b]Hawaiian coot destroys 1 egg, 3 eggs flood; nest was abandoned after flood. Adult coot destroys remaining 3 eggs.
[c]Incubated to full-term; possibly inviable eggs.
[d]Six nests were incubated to full-term, later self-depredated for unknown reasons; one nest was abandoned after visitation from a Feral Cat (*Felis catus*), no eggs were taken.
[e]Later a Hawaiian Common Gallinule (*Gallinula galeata sandvicensis*) destroys the single egg.

Table 4. Reproductive metrics for coot (HACO; n = 2), gallinule (HAGA; n = 6), and stilt (HAST; n = 15) in Hāmākua Marsh, Kailua, Hawai‘i, USA, 2023. 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%

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

Table 5. Predators captured by month at Hāmākua Marsh, Kailua, Hawai‘i, USA, 2023.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mongoose	2	5	2	1	6	1	2	5	7	2	1	1	35
Cat	0	0	0	0	0	0	0	1	0	1	1	1	3
Rat	7	4	4	5	1	4	1	1	3	1	5	9	45