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Hāmākua Marsh State Wildlife Sanctuary

Waterbird Report, 2021

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I. Overview

Hāmākua Marsh State Wildlife Sanctuary (heareafter ‘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.

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 most efficiently protect waterbirds.

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 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 2021 included disking three times per year using a Marsh Master MM-2XL equipped with the disking attachment. Disking occurred in late January, early September, and middle of December. This was the third consecutive year the habitat was altered three times (Table 1). Usually the interior wetland area is 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).

Mechanical manipulation was incorporated to minimize much of 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 2021, water levels ranged from 0–21.6, 13.2–30.0, 0–22.8, and 0–25.2 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 monthly and ranged from 2–66, 1–11, 1–42, and 2–15 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 2005–2021, 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 2021. Mean abundances (range) for coots were 35.0 individuals (20–55), gallinules were 56.9 individuals (30–94), and stilts were 41.0 (15–75) 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 B, C, and A, respectively. The average endangered waterbird per acre was 5.7 individuals.

Habitat Use.—Habitat utilization differed by species. The Hawaiian Coot was found most often in stream with 36.5% of the observations; the Hawaiian Gallinule was found most often in mudflat/vegetation with 50.7% of the observations; and the Hawaiian Stilt was found in most often in 0–3" water with 62.8% 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 2021 ranged from 13–91%, 44–96%, and 21–100% for coots, gallinules, and stilts, respectively. For 2021 coots, gallinules, and stilts had an overall fledging success rate of 13%, 47%, and 27%, respectively (Table 2). Fledging success rate in 2021 for coots, gallinules, and stilts was below the pooled averages (52%, 74%, and 64%, respectively). Coot fledging recruitment was 2 fledglings which was tied for the fifth lowest recorded recruitment for coots. The annual average recruitment for coots was 5.6 fledglings per year. Gallinule fledging recruitment was 16 fledglings which is below the annual average recruitment of 34.2 fledglings per year. Stilt fledging recruitment was 10 fledglings which is below the annual average recruitment of 11.6 fledglings per year. Fledgling recruitment in 2021 compared to the 17-year pooled average was 36%, 47%, and 86% for coot, gallinule, and stilt, respectively; meaning all waterbirds were below to extremely below average in fledgling recruitment.

3. Recommendations

Further study is necessary to identify causes of chick mortality to determine if management strategies can mitigate for chick loss. Low fledging success rate for coots, gallinules, and stilts suggests potential for multiple causes of chick mortality. Further investigation of cause-specific chick mortality will continue in 2022 under the Competitive State Wildlife Grant project and will aid in understanding the ability management has on influencing chick mortality (i.e., predation, flooding, disease, starvation, toxicants, or exposure). Many potential causes of chick death may not benefit from management objectives, but we must determine the actions, if any, that will aid in chick survival.

Specific habitat mapping would help the Wildlife Biologist determine if the waterbirds are using microhabitat proportionate to availability and how the frequency of habitat manipulations affects microhabitat availability. The Wildlife Biologist provides the largest amount of influence by altering the habitat by controlling plant cover. In the long-term, understanding habitat proportions as it relates to waterbird abundances could aid in optimizing habitat for a particular waterbird species or group of species. In 2022, habitat preferences for nest locations will be compared with randomly available habitat to determine if nesting habitat is distinguishable from habitat characteristics of randomly selected habitat options. Determining nest habitat characteristics will inform the Wildlife Biologist on management techniques to increase or decrease nesting habitat for each waterbird species.

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 a given 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 February through December 2021. 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.

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 nest surveys were conducted from January through December 2021. Nests were found from February 18 to May 27 (in addition: 1 nest on September 7 and 1 nest on December 28), March 8 to June 3, and April 21 to July 8 for the Hawaiian Coot, Hawaiian Gallinule, and Hawaiian Stilt, respectively. During the period of January through December 2021, 29 coot, 40 gallinule, and 20 stilt nests were observed (Figure 6). Out of 89 nests observed, Basin B contained the most nests (n = 33), then Basin A (n = 23), Basin C (n = 23), and Basin D (n = 10). Coot nests were found most often in Basin B (34%); gallinule nests were found most often in Basin B (38%); and stilt nests were most often found in Basin C (45%; Figure 6).

Nests observed peaked for coot and gallinule in April with coot and gallinule nests declining gradually ending in June, and stilt nests observed peaked in June, and by August no nests were found for all species (Figure 6). Coots nested from February through May, gallinules nested from March through June, stilts nested from April through July. Coots had two more nests one each in September and December (Figure 6). The coot nests (n = 2) observed during the dry season followed increased water levels in Basins A and B (Figure 7).

<u>*Overall Nest Outcomes*</u>

Out of 89 nests discovered, 56% (n = 50) produced at least one chick, 6% (n = 5) failed due to predation or partial predation, 3% (n = 3) failed due to flooding, 17% (n = 15) failed due to abandonment, 8% (*n* = 7) failed for unknown reasons, and 10% (*n* = 9) had unknown fates (Table 3).

<u>*Outcomes of Nests Monitored with Cameras*</u>

Out of 89 nests, 58 (65%) had a camera placed on them. Cameras were placed on 55%, 65%, and 80% of coot (*n* = 16), gallinule (*n* = 26), and stilt (*n* = 16) nests, respectively. Of the 58 nests with cameras, 74% (*n* = 43) produced at least one chick, 9% (n = 5) failed due to predation or partial predation, 15% (*n* = 9) failed due to abandonment, and 2% (*n* = 1) failed for unknown reasons (Table 3).

Reproductive Success.—We observed 9 coot, 16 gallinule, and 10 stilt broods; and 2 coot, 12 gallinule, and 4 stilt broods produced ≥1 fledgling (Table 4). The number of broods observed per nest were 0.3, 0.4, and 0.5 broods for coots, gallinules, and stilts, respectively. The number of fledglings per brood was 0.2, 1.0, and 1.0 fledglings for coots, gallinules, and stilts, respectively. The number of fledglings per nest was 0.1, 0.4, and 0.5 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 69% and an average clutch size of 4.7 eggs per nest.

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 above average nesting success for gallinules at 81% and an average clutch size of 5.0 eggs per nest.

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 2021, Hāmākua Marsh had a stilt nesting success of 63%. The nesting success for Hāmākua Marsh is 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 2021 to nesting seasons 2018 and 2019 (nesting success 58% combined), nesting success was average.

<u>*Outcomes of Nests Monitored with Cameras*</u>

Predation by conspecific and heterospecific waterbirds was estimated at about 10–17% for all nests monitored with cameras. Of nest failures, 9 of 15 (60%) nests possibly failed due to inter- or intraspecies competition. Of the coot nests that failed due to predation, one nest was destroyed by a coot and two nests were abandoned for unknown reasons (3/5 [60%] failed nests caused by potential competition). Of the gallinule nests that failed due to predation, two nests were destroyed by a gallinule and one nest was abandoned for unknown reasons (3/4 [75%] failed nests caused by potential competition). Of the stilt nests that failed due to predation, two nests were destroyed by a stilt and one nest was destroyed by a gallinule (3/6 [50%] failed nests caused by potential competition). Competition seems to be the main cause for failed nests (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). At Hāmākua Marsh coots had 0.2 fledglings per brood, gallinules had 1.0 fledglings per brood, and stilts had 1.0 fledglings per brood. Fledglings per brood observed is below average 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 2022, 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, 65% of nests had a camera placed to monitor the nest fate, and 90% of all waterbird nests a fate could be determined due to frequent twice weekly nest checks. However, an additional 8% of nests the fate could only be determined as a failure with an unknown cause. The goal for 2022 will be to setup as many cameras on nests as possible. This is largely determined by the amount of waterbird nests active temporally and spatially as Kawainui Marsh is included in this study. We do have an additional 8 cameras that will aid in documenting fates of all waterbird nests and will borrow nest cameras from UH. Nest failures due to parental abandonment remain difficult to ascertain the actual cause for leaving the nest.

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 chick per chick brood was affixed with a radio transmitter (Holohil BD-2), if the chick in the brood had perished another chick within the same brood was fitted with another transmitter. Hawaiian Stilt 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. Chicks were monitored through radio telemetry on a subset of the stilt chick population. 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.

<u>Chick Growth Curves</u>

Chicks were weighed and re-weighed to the nearest gram to determine growth rate relative to survival.

2. Results

Chick Monitoring.—In 2021, 37 stilt chicks hatched from an available 68 eggs (54%). Of the 37 chicks that hatched only 19 (51%) chicks survived to transmitter or banding size (typically 7−10d of age). Twelve chicks received a transmitter from eight separate broods. Of the 12 chicks that were equipped with a transmitter only 10 chicks received leg bands, meaning two chicks perished before they could reach the appropriate size for banding. An additional seven chicks received only leg bands, but no transmitter. Of the 19 chicks closely monitored with bands and transmitters, 10 (27%) chicks survived to the fledgling stage.

Chick Survival (Transmitters Equipped; *n* = 12)

Of the 12 stilt chicks marked with a transmitter six (50%) chicks survived. Of the six stilt chick deaths, 4 (67%) could be attributed to possible predation (3 bodies never recovered and 1 chick had puncture wounds on the neck); the other two deaths were due to starvation (33%).

Chick Survival (Plastic Leg Bands Only; *n* = 7)

Of the 7 chicks monitored with bands only, four (57%) chicks survived. Of the three stilt chicks that died, two were recovered and likely died of botulism/starvation (67%). One chick was never recovered and went missing the day after banding the chick (18d post-hatch), possible predation event likely (33%).

Chick Growth Curves

Chicks were weighed and re-weighed to determine growth rate relative to survival. Chicks that failed ($n = 9$) had an average of 2.7 mass measurements per bird and chicks that survived ($n = 10$) had 5.4 mass measurements per bird. The growth rate of chicks that survived was significantly greater than chicks that perished (ANOVA; $p = 0.003$; Figure 8).

3. Discussion

Chick Monitoring.—Stilt chick mortality was high at 53% with all marked chicks ($n = 19$) and similar when looking at the chicks outfitted with a transmitter ($n = 12$) at 50%. An average of 25.1d (14–42d) elapsed since hatch for stilt chicks that failed. All starvation events occurred during a period of 10 days (June 28–July 7) when the water levels were decreasing rapidly and food availability was likely scarce. Three of the four stilt chick bodies were never recovered that perished due to possible predation events. In all those possible predation events, chick age averaged 31d (19–42d); all the weights for stilt chicks that possibly succumbed to predation had average body mass when compared to the successfully fledged cohort and was found always increasing relative to age. The stilt chick that was recovered and had two puncture wounds on the neck had a decrease in weight from 19d to 30d (-7g) and later died at 31d. The possibility of this chick perishing is likely due to attacks from other adult stilts as this chick likely dispersed to new territory to find food and may have been mobbed to death.

4. Recommendations

Chick Monitoring.—We had no success in identifying predators responsible for predation of stilt chicks. All potential stilt chick predation events resulted in transmitters falling off and were not consumed. In 2022, we plan to deploy passive infrared cameras in the vicinities of stilt chicks equipped with transmitters. Often the stilt chicks are found in the same general location and home ranges seem to be small, so deploying an array of cameras around stilt chicks could help managers identify the predators responsible for stilt chick deaths.

d. Long-term Waterbird Population Analysis

1. Results

Survey.—A total of 213 waterbird surveys were conducted during 2017–2021 (*n*=25, *n*=44, *n*=45, *n*=49, *n*=50, respectively). The average coot abundance for those years were 14, 18, 30, 40, and 35 individuals; the average gallinule abundance was 69, 54, 72, 82, and 57 individuals; and the average stilt abundance was 20, 26, 40, 46, and 41 individuals, respectively (Figure 9).

2. Discussion

The populations of coots, gallinules, and stilts at Hāmākua Marsh increased from 2018–2020 and decreased in 2021; coot, gallinule, and stilt populations decreased on average 12%, 30%, and 11%, 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

Habitat management in 2022 will remain similar to 2019–2021, applying the disking technique three times per year focusing on leaving islands of pickleweed (*Batis maritima*) and saltmarsh bulrush (*Bolboschoenus maritimus*) for coot and gallinule nesting habitat and creating mudflat habitat for stilts. Creating ideal habitat for all three endangered waterbirds is accomplished by maintaining the pickleweed on the shallowest areas of all the basins during the wet season, which minimizes pickleweed re-growth and creates mudflat once the water recedes in the drier months. The deeper portions of all the basins were disked minimally to leave islands of pickleweed surrounded by deeper waters in the wet months and progressively shallower waters in the drier months. The pickleweed in the shallow water sections is completely disked, whereas, in deeper waters only pickleweed edges are completely disked to maintain the vegetation islands.

IV. Predator Control

a. Methods

DOC-200 kill traps (*n* = 20) and one conibear cat-kill trap were distributed along the road in the interior that paralleled the marsh (Figure 10). 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 48 small Indian mongooses (*Herpestes javanicus*), 75 rats (*Rattus* spp.), and 10 cats (*Felis catus*; Table 5).

c. Recommendations

Mongoose take in 2021 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 statistical significant difference in trapping success; however, DOC-200 traps outperformed live traps in our study (Roerk et al. *in review*). Predator control will remain the same for 2022.

At Hāmākua Marsh mongoose control seems less necessary than at Pouhala Marsh. 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 2022

Hāmākua Marsh provides adequate habitat 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 marshes 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 2022, we will continue the final year of the two-year Competitive State Wildlife Grant project for stilts. Radio telemetry will be used to further understand the chick stage of the Hawaiian Stilt. We will aim to improve identification of predators as we failed to determine predators responsible for 4 of 6 transmittered stilt chicks. Once sources of mortality are identified mitigation measures can be initiated.

In addition, we will begin a similar project studying cause specific mortality in Hawaiian Gallinule chicks with a PBHJV grant. This project is analogous to the stilt chick mortality study.

Radio telemetry will be used to track chicks at their most vulnerable stage and aim to determine cause of death and provide a survivorship model for the Hawaiian Gallinule.

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VII. Appendix

a. List of Figures and Tables

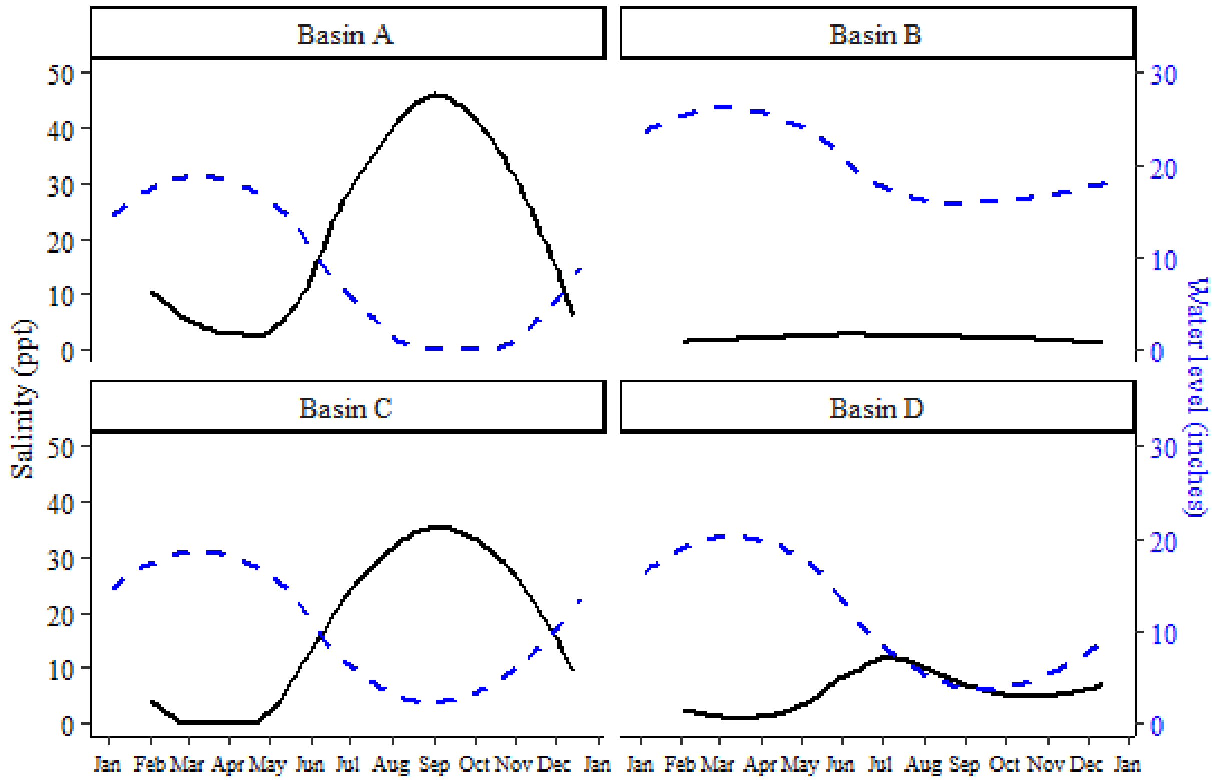

Figure 1. Water level and salinity in Basins A, B, C, and D in Hāmākua Marsh State Wildlife Sanctuary on O‘ahu, Hawai‘i. The blue dashed line is water level and the red solid line is salinity.

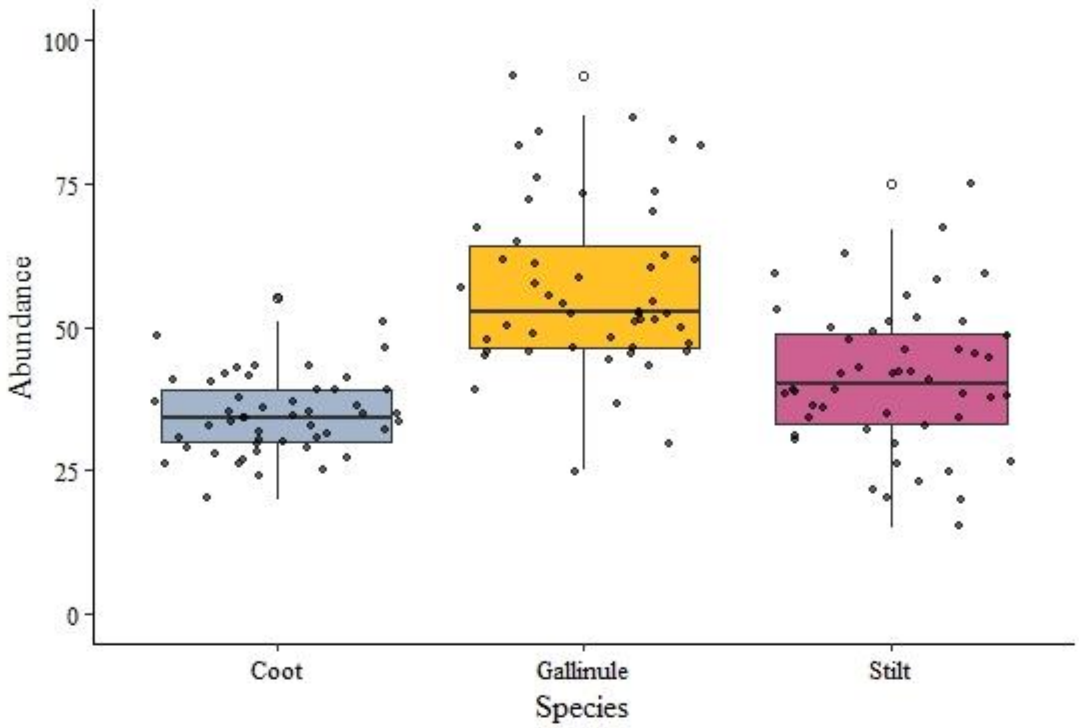

Figure 2. Boxplot displaying median values and interquartile ranges for coots, gallinules, and stilts. Black points represent abundances for each individual survey (*n* = 50). Open circles are outliers and whiskers represent minimum and maximum.

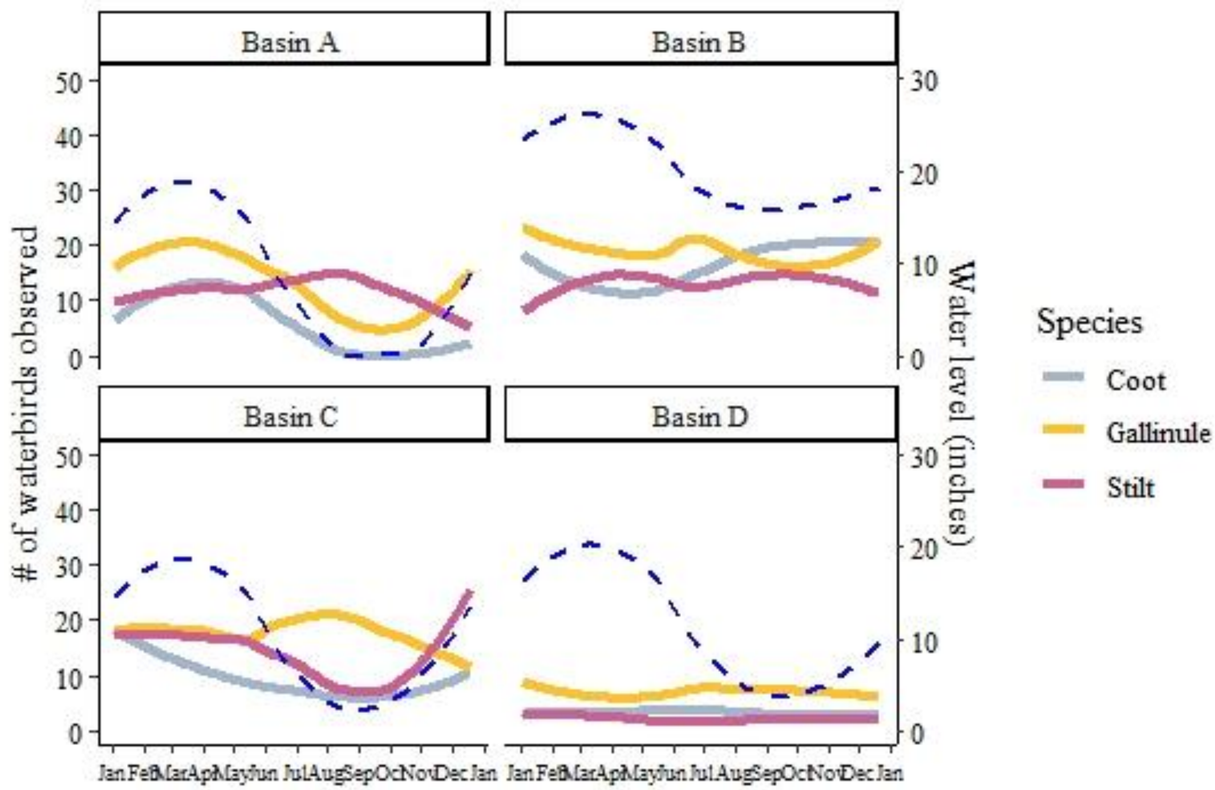

Figure 3. Waterbird abundance by species, basin, and month. The blue dashed line is the water level in inches.

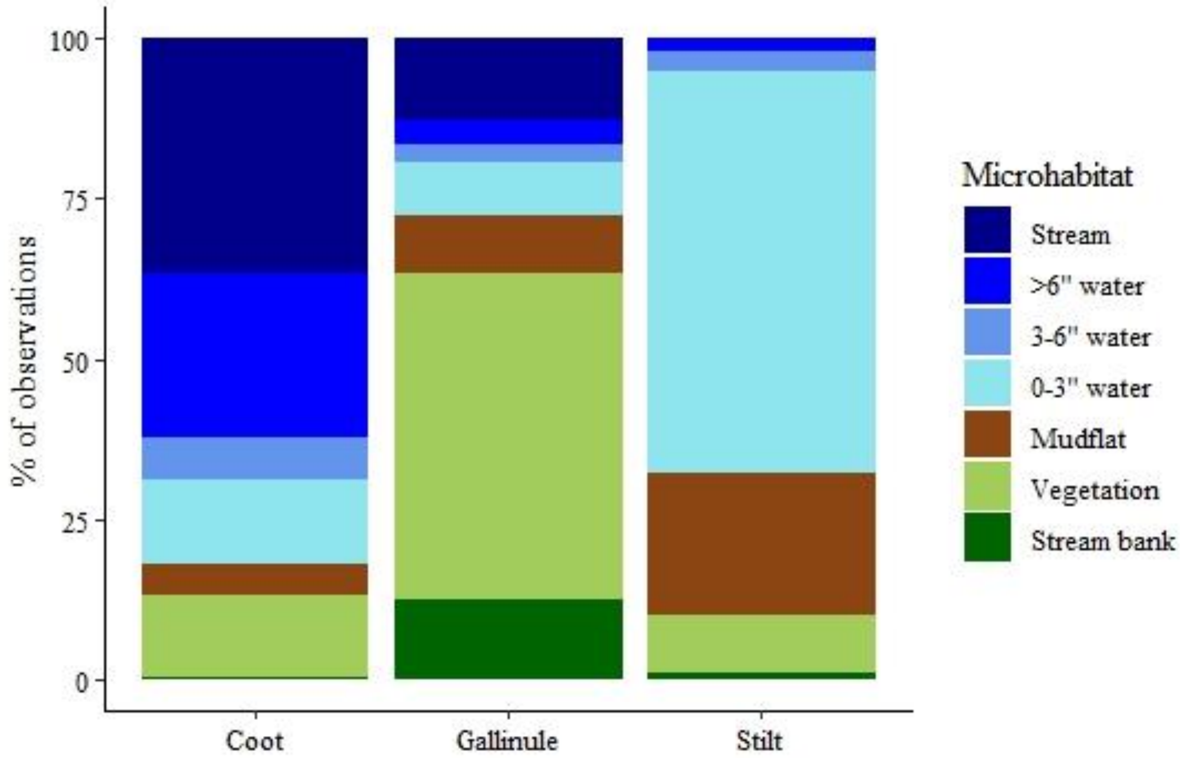

Figure 4. Percent of observations for coots, gallinules, and stilts in seven microhabitats found within Hāmākua Marsh State Wildlife Sanctuary on Oʻahu, Hawaiʻi.

Figure 5. Nest distribution map for Hāmākua Marsh State Wildlife Sanctuary. Pictured are 29 coot (A-9, B-10, C-6, D-4), 40 gallinule (A-11, B-15, C-8, D-6), and 20 stilt (A-3, B-8, C-9, D-0) nests observed in 2021. Nest surveys were conducted weekly and biweekly.

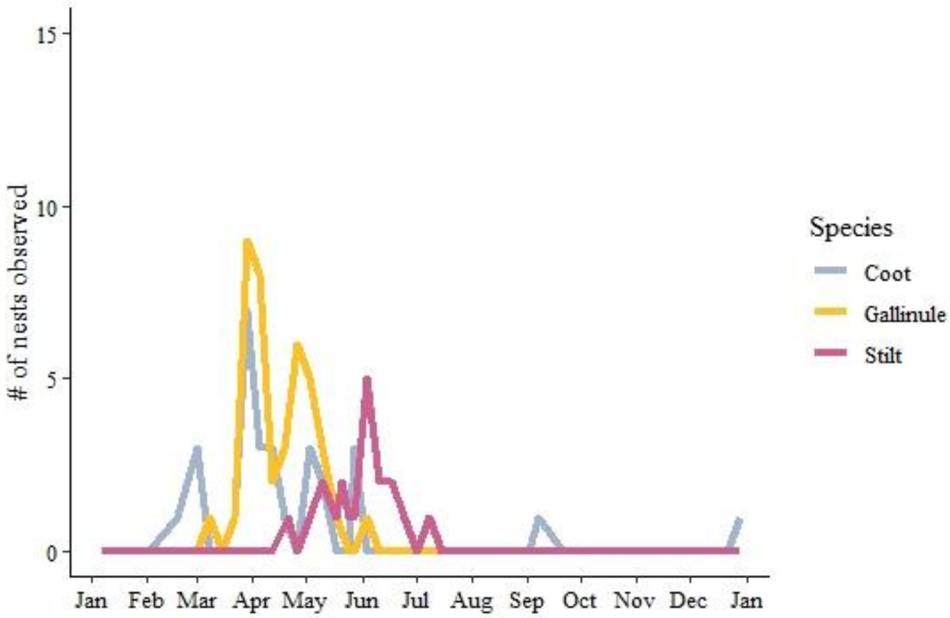

Figure 6. Number of nests found by nest survey. One nest survey was conducted biweekly from January–February, August–December 2021 and weekly nest surveys were conducted March–July 2021.

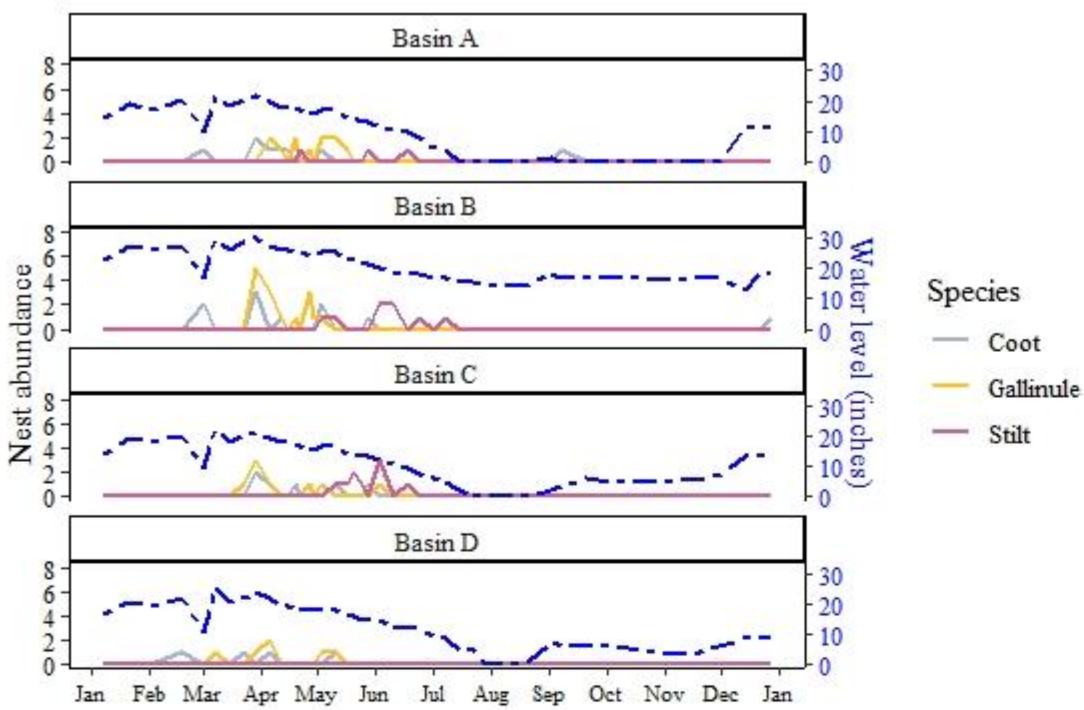

Figure 7. Nest observations and average water level by species and basin from January–December 2021 at Hāmākua Marsh State Wildlife Sanctuary, Oʻahu, Hawaiʻi. The blue dashed line is the water level (inches) during each survey.

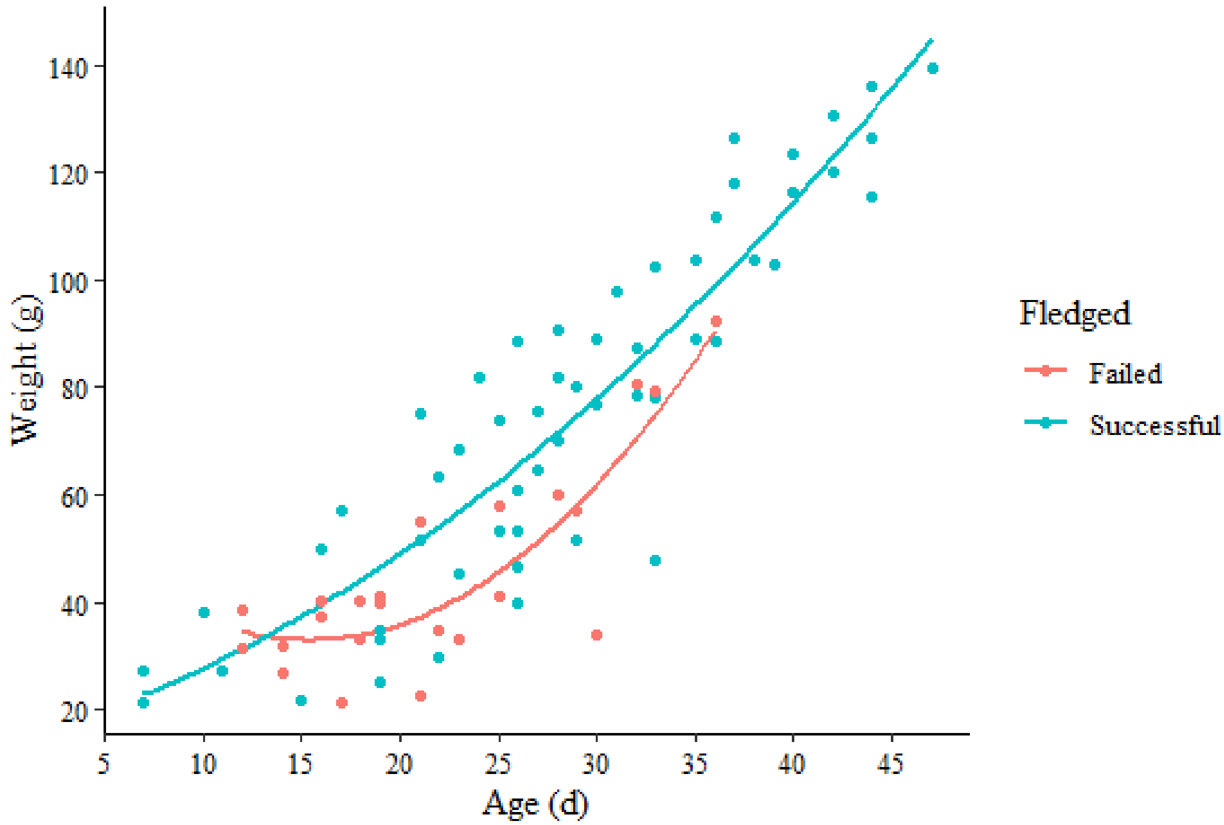

Figure 8. Hawaiian stilt chick growth curve comparing growth rate of fledged versus failed chicks (ANOVA; p = 0.003; R^2 = 0.82).

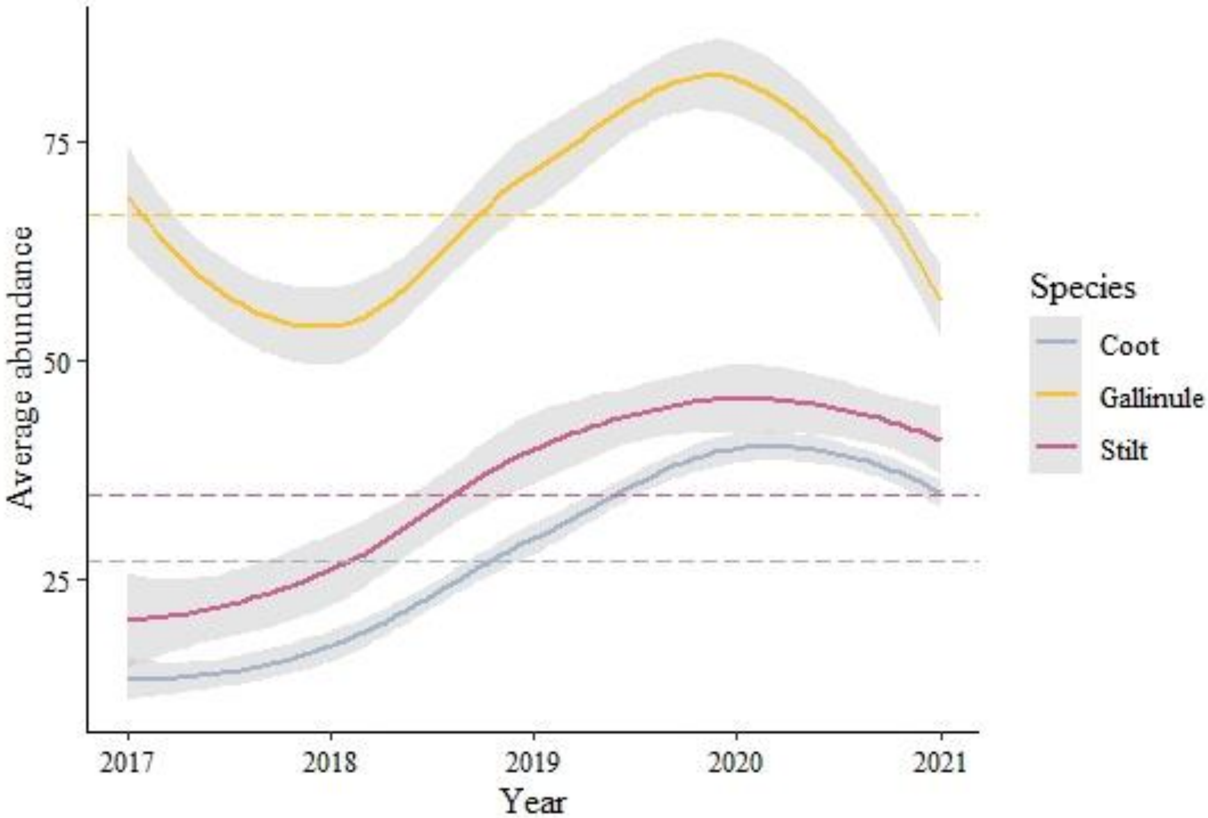

Figure 9. Average abundances for coots, gallinules, and stilts from 2017 through 2021 at Hāmākua Marsh State Wildlife Sanctuary, Oʻahu, Hawaiʻi. Gray shaded areas are 95% confidence intervals, horizontal dashes (color coded by species) represent the overall averages for each species over the span 2017–2021.

Figure 10. Map of trap distribution for DOC-200 and conibear traps at Hāmākua Marsh, O‘ahu, Hawai‘i.

Table 1. Habitat manipulation operations and techniques used within the wetlands at Hāmākua Marsh Wildlife Sanctuary, Kailua, Hawai‘i, USA from 2003–2021.

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.

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 2005–2021 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
Total	**181 (40)**	**109**	**60%**	**0.9**	**883 (70)**	**645**	**73%**	**1.5**	**308 (51)**	**198**	**64%**	**1.4**

*Chicks # 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 2021.

		Coot (*n*=29)	Gallinule (*n*=40)	Stilt (*n*=20)	Total (*n*=89) [a]
Camera		**16**	**26**	**16**	**58**
Nest parameters					
	Hatched (%HS)	11 (69) [b]	22 (81) [c]	10 (63)	43
	Clutch size	4.7	5.0	3.9	
Nest failures					
Predator	Hawaiian Coot (*Fulica alai*)	1			1
	Hawaiian Common Gallinule (*Gallinula galeata sandvicensis*)		2		2
Other failure	Abandoned	2 [d]	2 [e]	5 [f]	9
	Partial predation	1 [g]		1 [h]	2
	Unknown	1 [i]			1
No camera		**13**	**14**	**4**	**31**
Nest parameters					
	Hatched (%HS)	4 (31)	3 (23)		7
	Clutch size	4.1	3.7	1.5	
Nest failures					
Other failure	Abandoned	2 [d]		4 [d]	6
	Flooded	2	1		3
	Unknown	1 [j]	5 [k]		6
Unknown		4	5		9

[a] Sum of independent hatching and nest failure events.
[b] Partial depredation of one nest by unknown predator.
[c] Partial depredation of two nests; one depredated by gallinule and one depredated by a small Indian mongoose (*Herpestes javanicus*).
[d] Abandoned for unknown reason.
[e] One abandoned for unknown reason; one abandoned after full incubation period, eggs unviable.
[f] Three abandoned after full incubation period, eggs unviable; one abandoned after parental male depredated own nest; and one abandoned due to conspecific skirmish.
[g] One egg depredated, remaining egg incubated to full term and never hatched.
[h] Gallinule depredated one egg in nest, stilt continued incubation until subsequent visit by gallinule; stilt abandoned nest. A rat is observed taking 3 remaining eggs serially over 3 consecutive nights.
[i] Eggs were completely gone before expected hatching date.
[j] Possible depredation event; nest found with one egg, subsequent visits had zero eggs.
[k] Three nests were discovered with all eggs cracked (prior depredation before discovery); one nest was found with one egg, subsequent visits had zero eggs; and one nest was cold and had one cracked egg at time of expected hatch.

Table 4. Reproductive metrics for coot (HACO; *n* = 36), gallinule (HAGA; *n* = 26), and stilt (HAST; *n* = 35) in Hāmākua Marsh, Kailua, Hawai'i, USA, 2020. 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	60%	71%	50% [a]	13%	48%	27% [a]	7%	30%	15% [a]

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

Table 5. Predators captured by month at Hāmākua Marsh, Kailua, Hawai'i, USA, 2021.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mongoose	1	3	4	2	1	6	9	7	8	2	3	2	48
Cat	0	2	0	1	1	1	1	1	0	2	0	1	10
Rat	11	13	8	10	9	6	2	1	6	2	6	1	75