Department of Land and Natural Resources

Division of Forestry and Wildlife

O'ahu Branch

2135 Makiki Heights Drive • Honolulu • HI • 96822

(808) 973-9788

Hāmākua Marsh State Wildlife Sanctuary

Waterbird Report, 2020

Prepared by:

Aaron J. Works, Wildlife Biologist, Division of Forestry and Wildlife

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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 (Figure 1).

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 loafing 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

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 (Figure 1). 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 2020 included disking two times and tilling one time per year using a Marsh Master MM-2XL equipped with the disking or tilling attachment. Disking occurred in early February and late July, whereas tilling occurred in late September. This was the second consecutive year the habitat was altered three times (Table 1). Usually the interior wetland area is manipulated once during the year, yet in 2019 and 2020 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 Hamakua Marsh can grow densely when not mechanically manipulated potentially prohibiting waterbirds from accessing prey.

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 1). 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 2007–2020, 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 49 surveys were conducted at Hāmākua Marsh in 2020. Mean abundances (range) for coots were 40.0 individuals (26–55), gallinules were 82.2 individuals (51–114), and stilts were 45.7 (8–94) individuals per survey (Figure 2). The average abundances of coots, gallinules, and stilts were highest in Basins B, A, and C, respectively (Figure 3). The average density of coots, gallinules, and stilts per acre was highest in Basins B, A, and C, respectively. The average endangered waterbird per acre was 7.2 individuals.

Habitat Use.—Habitat utilization differed by species. The Hawaiian Coot was found most often in stream with 36.6% of the observations; the Hawaiian Gallinule was found most often in mudflat/vegetation with 54.5% of the observations; and the Hawaiian Stilt was found in most often in 0–3" water with 58.5% 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 2007 to 2020 ranged from 50–82%, 44–97%, and 8–87% for coots, gallinules, and stilts, respectively. For 2020 coots, gallinules, and stilts had an overall fledging success rate of 62%, 68%, and 73%, respectively (Table 3). Fledging success rate in 2020 for coots and gallinules was below the pooled average (64% and 75%, respectively), but above average for stilts (64%). Coot fledging recruitment was 29 fledglings which was the highest recorded recruitment for coots; the next highest was 9 fledglings recorded in 2010 and 2011. The annual average recruitment for coots was 7.5 fledglings. Gallinule fledging recruitment was 30 fledglings which is below the annual average recruitment of 38.8 fledglings. Stilt fledging recruitment was 24 fledglings which is above the annual average recruitment of 12.4 fledglings.

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 commence in 2021 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.

b. Nest Surveys

1. Methods

Nest Monitoring.—Nests were located during routine monthly or biweekly surveys using an area-search survey. During area-search surveys, a team of 2-3 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 1). During non-stilt nesting season focus was made on searching coot and gallinule nest habitat.

Waterbird nests were monitored from January through December 2020. 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 1” x 1” wooden post one meter long, fixed with a 40° wedge, and secured with a camera strap. 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 bi-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.—Twenty-two surveys were conducted from January through December 2020. Nests were found from January 24 to November 12, February 6 to November 12, and April 14 to June 18, 2020 for the Hawaiian Coot, Hawaiian Gallinule, and Hawaiian Stilt, respectively. During the period of January through December 2020, 36 coot, 26 gallinule, and 35 stilt nests were observed (Figure 6). Out of 97 nests observed, Basin B contained the most nests (*n* = 42), then Basin A (*n* = 26), Basin C (*n* = 25), and Basin D (*n* = 6). Coot nests were found most often in Basin B (64%); gallinule nests were found equally in Basins A and B (77%); and stilt nests were most often found in Basin C (54%; Figure 6).

Nests observed peaked for all species in April with coot and gallinule nests declining drastically, and stilt nests observed remaining static through June, and by July no nests were found for all species (Figure 6). Stilts nested from April through June, whereas, coots and gallinules nested year-round (Figure 6). The coot and gallinule nests observed during the dry season followed increased water levels in Basins A, B, and C (Figure 7).

<u>Overall Nest Outcomes</u>
Out of 97 nests discovered, 38% (*n* = 37) produced at least one chick, 3% (n = 2) failed due to depredation, 6% (*n* = 6) failed due to flooding, 10% (*n* = 10) failed due to abandonment, and 43% (*n* = 42) had unknown fates (Table 4).

<u>Outcomes of Nests Monitored with Cameras</u>
Out of 97 nests, 31 (32%) had a camera placed on them. Cameras were placed on 36%, 31%, and 29% of coot (*n* = 13), gallinule (*n* = 8), and stilt (*n* = 10) nests, respectively. Of the 31 nests with cameras, 58% (*n* = 18) produced at least one chick, 6% (n = 2) failed due to depredation, 13% (*n* = 4) failed due to flooding, 16% (*n* = 5) failed due to abandonment, and 7% (*n* = 2) had unknown fates (Table 4).

Reproductive Success.—We observed 26 coot, 17 gallinule, and 18 stilt broods and 19 coot, 17 gallinule, and 13 stilt broods produced ≥1 fledgling (Table 5). The number of broods observed per nest were 0.7, 0.7, and 0.5 broods for coots, gallinules, and stilts, respectively. The number of fledglings per brood was 1.1, 1.8, and 1.3 fledglings for coots, gallinules, and stilts, respectively. The number of fledglings per nest was 0.8, 1.2, and 0.7 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 64% and an average clutch size of 4.8 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 average nesting success for gallinules at 63% and a below average clutch size of 4.8 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 2020, Hāmākua Marsh had a stilt nesting success of 60%. 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 2020 to nesting seasons 2018 and 2019 (nesting success 58% combined), nesting success was average.

Fledging Success.—Stilt fledging success in 2020 was 73%. For 2018 and 2019, fledging success was reported as 44% and 74%, respectively. Problems with reporting chicks and fledging success are that older chicks have a higher probability of detection and young chicks that fail due to various reasons have a lower chance of being observed and may never be recorded into the Wildlife Biologist's survey data. By tracking all nests with cameras an accurate chick count can be recorded and compared to observed fledgling numbers. I suspect that potentially 50−75% of the chicks that hatched were never recorded and perished before the Wildlife Biologist could observe them. In 2020, the average egg clutch for stilts was 3.5 eggs per nest, which equates to 122 chicks. Accounting for the nests with known abandonment or partial hatches it was deduced that 106 chicks were possible, and 33 total chicks (69% failure rate) were observed in the 2020 nesting season.

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 1.1 fledglings per brood, gallinules had 1.8 fledglings per brood, and stilts had 1.3 fledglings per brood. Fledglings per brood observed is above average compared with other studies.

4. Recommendations

Nest Monitoring.—Bi-weekly surveys are needed to observe all the nests throughout the nesting season and continuing with bi-weekly surveys is recommended. In 2021, nest surveys will be conducted bi-weekly for the entire year and weekly for peak nesting season.

To determine nesting success and depredation events cameras are needed for monitoring nests. We have increased our camera inventory by nearly five times to capture a higher proportion of observed nests with a camera. Almost half of the nests observed no fate could be determined, largely due to the lack of cameras. Approximately, 94% of nests with a camera a fate was determined. The two exceptions were due to poor timing of camera placement as the two coot nests were previously abandoned (Table 3).

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) 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. Long-term Waterbird Population Analysis

1. Results

Survey.—A total of 163 waterbird surveys were conducted during 2017–2020 (*n*=25, *n*=44, *n*=45, *n*=49, respectively). The average coot abundance for those years were 14, 18, 30, and 40 individuals; the average gallinule abundance was 69, 54, 72, and 82 individuals; and the average stilt abundance was 20, 26, 40, and 46 individuals, respectively (Figure 8).

2. Discussion

The populations of coots, gallinules, and stilts at Hāmākua Marsh have increased over the last 4 years with the largest increases occurring in 2019 and 2020. The difference in management of Hāmākua Marsh during 2019–2020 has been the habitat manipulation techniques implemented beginning in 2019 and continued through 2020.

In 2017 and 2018 the pickleweed was mowed and dry areas were mechanically controlled using a skid steer with a tilling attachment in the dry season. The frequency of habitat manipulations was once per year.

Habitat manipulations in 2019 and 2020 included disking three times per year using a Marsh Master MM-2XL equipped with the disking attachment. Disking occurred in January, August and October and was the highest habitat management frequency recorded (Table 1). Usually the interior wetland area is manipulated once during the year, yet in 2019 and 2020 the habitat was selectively manipulated on three separate occasions mainly avoiding stilt nesting season (March–August).

Comparatively, Polhemus and Smith (2005) found that in 2003 and 2004 the average stilt abundance at Hāmākua Marsh was 25 and 25 individuals per survey, respectively. The mean stilt abundances in 2003–2004 (25 individuals combined) were similar to the mean abundances in 2017–2018 (23 individuals combined). The 1.9 times increase in stilt abundance in 2019–2020 (43 individuals combined) compared to prior years is most likely explained by the change in the frequency and technique of habitat manipulations. During the 2017–2020 seasons, predator control efforts remained similar or decreased. Other factors may have contributed to the increase in stilt abundance, but the shift in the strategy in habitat management remains the most plausible explanation for the sudden and direct increase following the alteration of the habitat manipulation technique applied to all basins at Hāmākua Marsh.

3. Recommendations

Habitat management should remain similar to 2019–2020, 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

The USDA-WS used 19 live traps to target the capture of mongoose and cats. The live trapping occurred from January to March 2020 and did not resume until June 16, 2020. When predator trapping resumed, DOFAW managed predator control efforts. The live traps were substituted for DOC-200 kill traps (*n* = 20) and were distributed along the road in the interior that paralleled the marsh (Figure 9). The DOC-200 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 were baited weekly to monthly with previously frozen fish or dry cat food mixed with either salmon oil, shellfish oil, or crayfish oil. Two cat kill-traps or chimney traps were deployed on September 3, 2020; each cat trap was installed with two conibears on each end with an entrance in the top and later modified for entrance on both ends of the trap. The cat traps were baited weekly to monthly with previously frozen fish or dry cat food mixed with either salmon oil or shellfish oil.

b. Results

Capture effort was reduced with no trapping in April, May, and the first half of June. DOC-200 kill traps were deployed on June 16, 2020 and two cat kill-traps were deployed on September 3, 2020. The USDA-WS trapped 20 small Indian mongooses (*Herpestes javanicus*) and DOFAW trapped 23 mongooses, 37 rats (*Rattus* spp.), and 8 cane toads (*Rhinella marina*; Table 6).

c. Recommendations

Predator control efforts in 2020 were minimal compared to other years. Mongoose take was well below the annual average mongoose take from 2007–2019 (127 mongooses).

Predator control efforts will continue as mongoose and cats are believed to prey mostly upon the chick stage of coots, gallinules, and stilts at this site. During nest surveys a mongoose scat was found containing feathers, bones, and a beak of a gallinule or coot chick, probably one to two weeks old.

The efficacy of live traps versus DOC-200 traps seems contrasting and warrants further study. In early 2021, we will conduct a side-by-side predator control study in Kawainui Marsh comparing the efficacy and efficiency of live traps and DOC-200 kill traps for mongoose control.

At Hāmākua Marsh mongoose control seems less necessary than at Kawainui Marsh. At Hāmākua Marsh, one of 31 nests (3%) monitored by a camera were depredated by a mongoose. In contrast, Kawainui captured on camera three of seven (43%) nests preyed upon by mongooses.

V. Conclusions and Goals for 2021

Hāmākua Marsh provides adequate habitat for all endangered waterbirds present on O‘ahu. 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 O‘ahu, and severely limits the marshes ability to sustain Hawai‘i. 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 2021, a two-year Competitive State Wildlife Grant project will begin. Radio telemetry will be used to understand the chick stage of the Hawaiian Stilt. This project aims to determine the role predators have on the survivorship of chicks. Once sources of mortality are identified mitigation measures can be initiated.

VI. Literature Cited

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VII. Appendix

a. List of Figures and Tables

Figure 1. Map of Basins A, B, C, and D in Hāmākua Marsh State Wildlife Sanctuary on O‘ahu, Hawai‘i. Inset map shows Hāmākua Marsh outlined in red situated on the windward side of the Ko‘olau Range in Kailua, Hawai‘i.

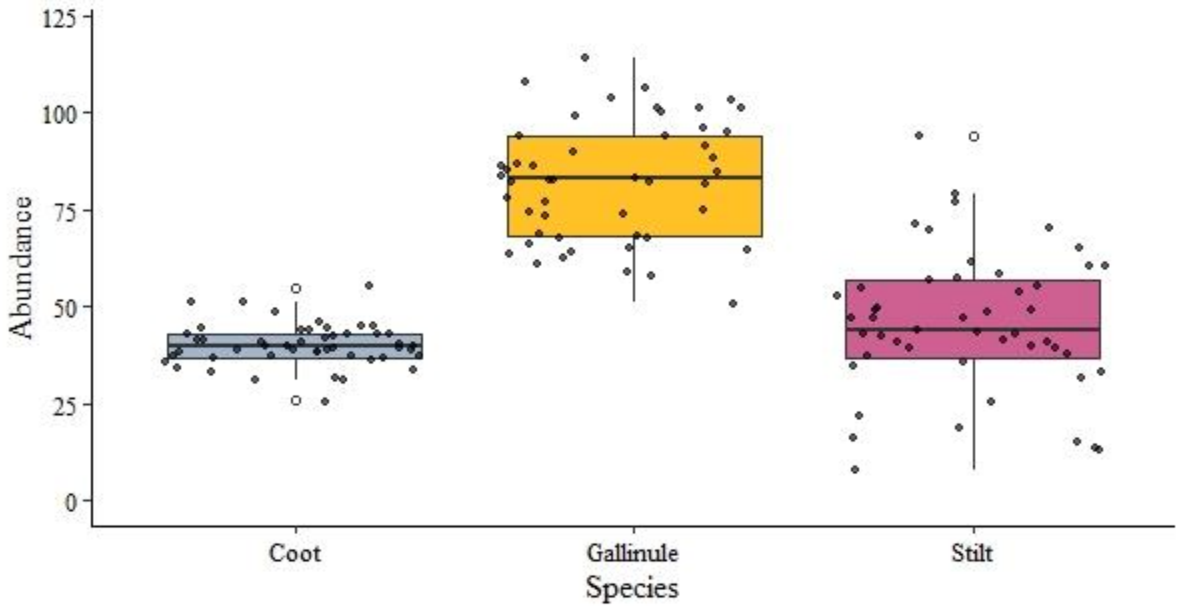

Figure 2. Boxplot displaying median values and interquartile ranges for coots, gallinules, and stilts. Black points represent abundances for each individual survey (n = 49). Open circles are outliers and whiskers represent minimum and maximum.

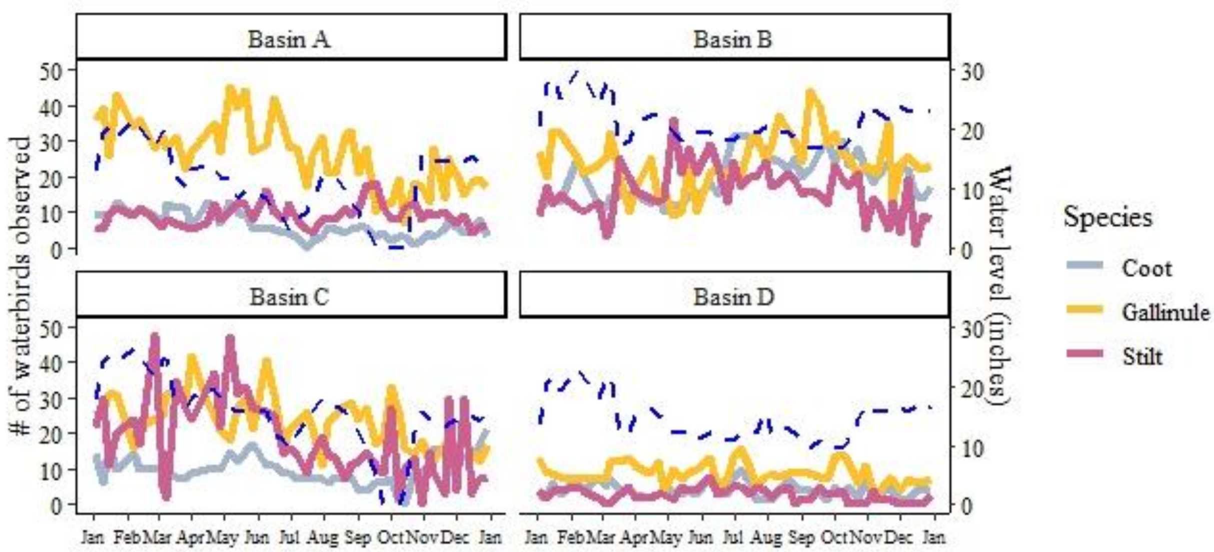

Figure 3. Waterbird abundance by species, basin, and month. The blue dashed line is the water level in inches.

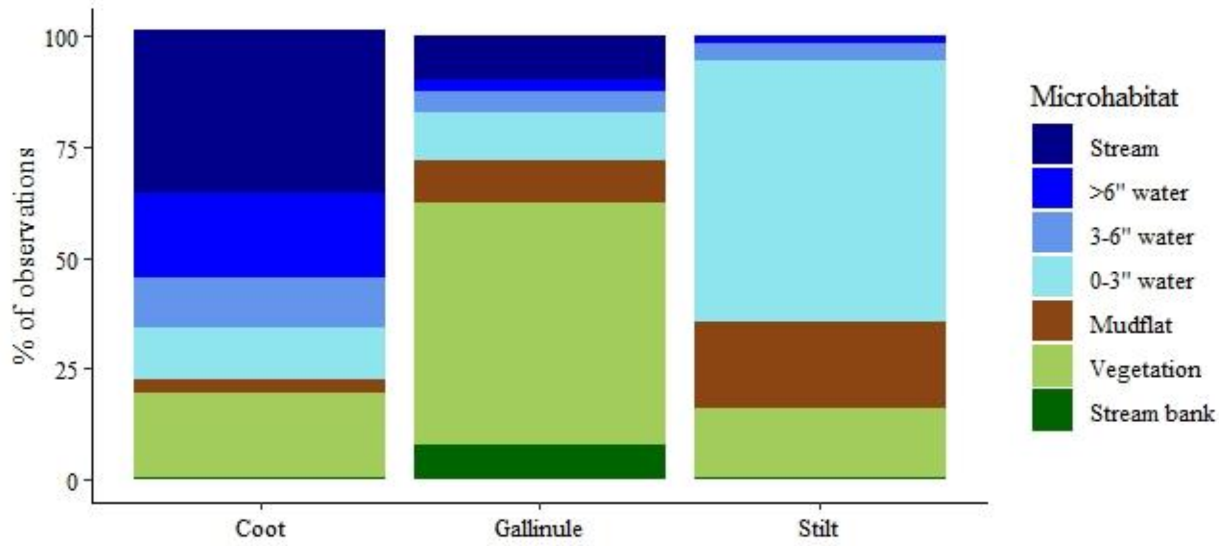

Figure 4. Percent of observations for coots, gallinules, and stilts in seven microhabitats found within Hāmākua Marsh State Wildlife Sanctuary on O‘ahu, Hawai‘i.

Figure 5. Nest distribution map for Hāmākua Marsh State Wildlife Sanctuary. Pictured are 36 coot (A-9, B-23, C-3, D-1), 26 gallinule (A-10, B-10, C-3, D-3), and 35 stilt (A-4, B-10, C-19, D-2) nests observed in 2020. Nest surveys were conducted monthly and biweekly.

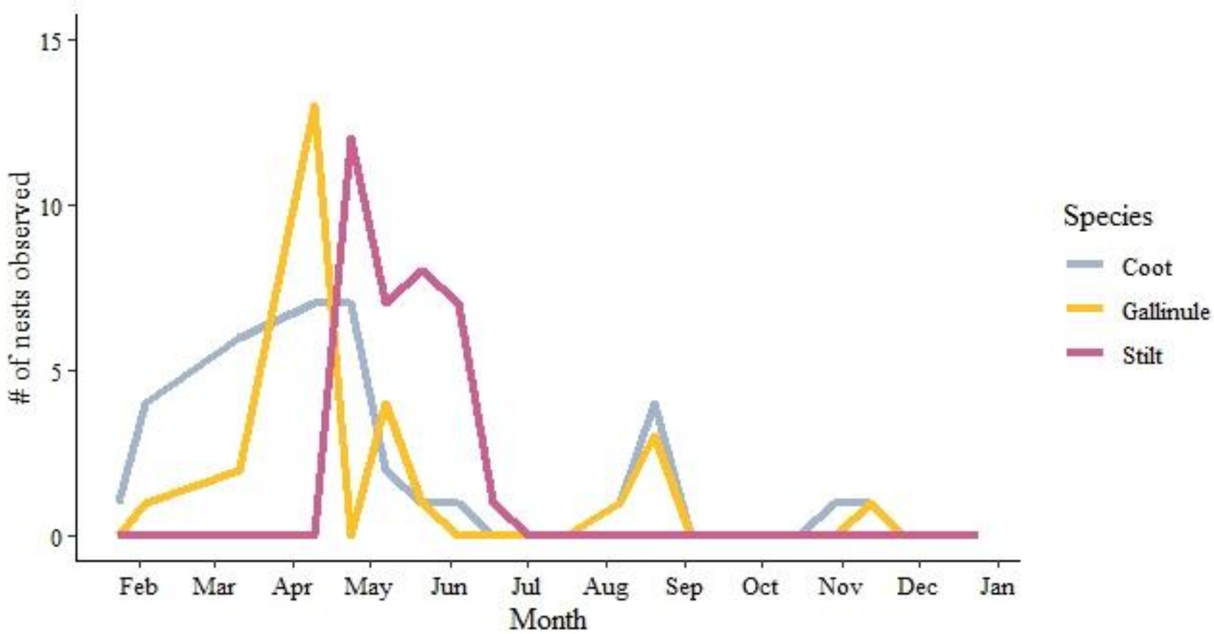

Figure 6. Number of nests found by nest survey. One nest survey was conducted each month from January–March 2020 and two nest surveys were conducted every month from April–December 2020.

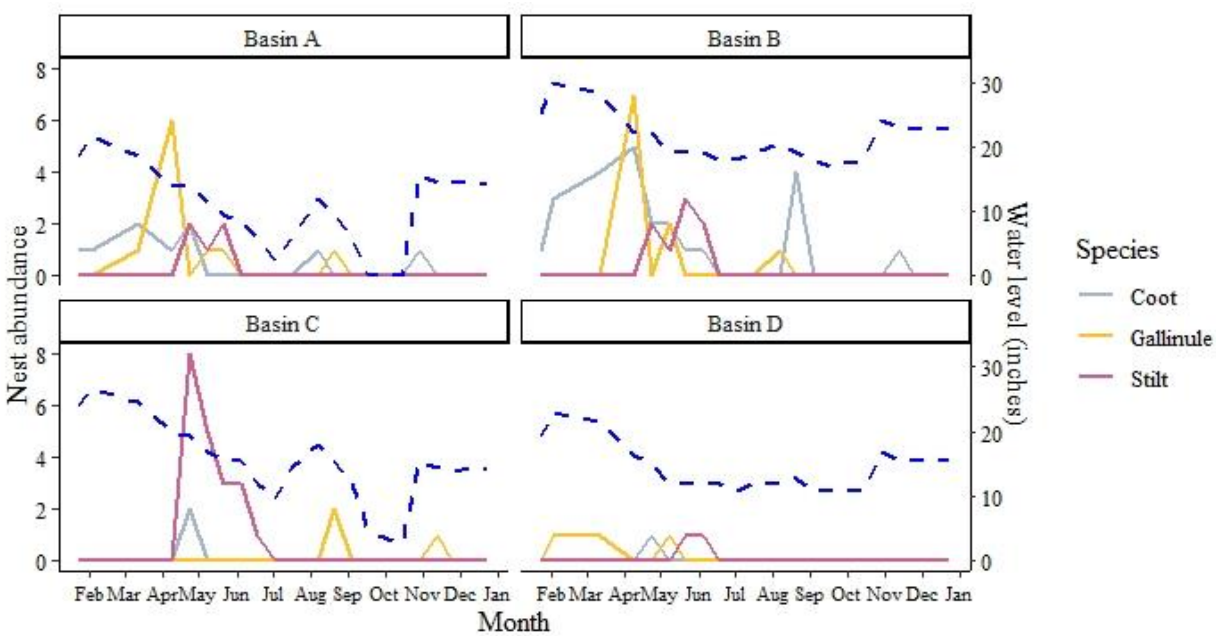

Figure 7. Nest observations and average water level by species and basin from January–December 2020 at Hāmākua Marsh State Wildlife Sanctuary, O‘ahu, Hawai‘i. The blue dashed line is the water level (inches) during each survey.

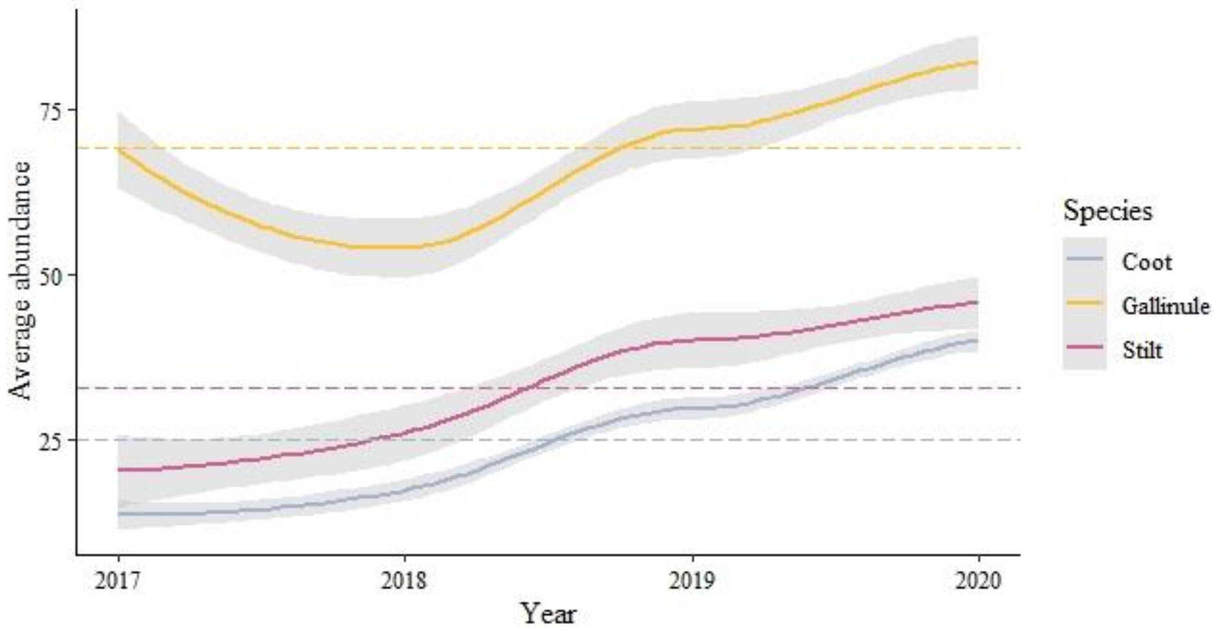

Figure 8. Average abundances for coots, gallinules, and stilts from 2017 through 2020 at Hāmākua Marsh State Wildlife Sanctuary, Oʻahu, Hawaiʻi. Gray shaded areas are 95% confidence intervals, horizontal dashes (color coded by species) represent the overall averages for each species over the span 2017–2020.

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

Table 1. Habitat manipulation operations and techniques used within the wetlands at Hāmākua Marsh Wildlife Sanctuary, Kailua, Hawaiʻi, USA from 2003–2020.

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.

Table 2. Nesting observations for Hawaiian Coot, Hawaiian Gallinule, and Hawaiian Stilt from January–December 2020 at Hāmākua Marsh State Wildlife Sanctuary, Kailua, Hawaiʻi, USA.

Date found	Nest ID	Species	Location	Eggs	Camera?	Status	Reason for failure
1/24/2020	C00-2020	Coot	A	3	y	Hatched	
2/3/2020	C01-2020	Coot	B	2	y	Hatched	
2/3/2020	C02-2020	Coot	B	5	y	Failed	Flooded
2/3/2020	C03-2020	Coot	B	5	y	Hatched	
2/13/2020	C04-2020	Coot	A	4	n	Unknown	
3/11/2020	C05-2020	Coot	A	4	y	Failed	Flooded
3/11/2020	C06-2020	Coot	A	5	y	Unknown	Camera placed late
3/11/2020	C07-2020	Coot	B	3	y	Unknown	Camera placed late
3/11/2020	C08-2020	Coot	B	3	n	Failed	Flooded
3/11/2020	C09-2020	Coot	B	2	n	Failed	Flooded
3/11/2020	C10-2020	Coot	B	4	y	Failed	Flooded
4/9/2020	C11-2020	Coot	C	2	n	Hatched	
4/9/2020	C12-2020	Coot	B	6	y	Failed	Abandoned
4/9/2020	C13-2020	Coot	B	1	n	Unknown	
4/9/2020	C14-2020	Coot	B	7	n	Hatched	
4/9/2020	C15-2020	Coot	B	6	n	Unknown	
4/9/2020	C16-2020	Coot	B	4	n	Unknown	
4/9/2020	C17-2020	Coot	A	6	n	Hatched	
4/23/2020	C18-2020	Coot	A	8	n	Unknown	
4/23/2020	C19-2020	Coot	B	6	n	Hatched	
4/23/2020	C20-2020	Coot	B	10	n	Unknown	
4/23/2020	C21-2020	Coot	C	5	n	Unknown	
4/23/2020	C22-2020	Coot	D	6	n	Hatched	
4/23/2020	C23-2020	Coot	C	5	n	Failed	Abandoned
4/28/2020	C24-2020	Coot	A	5	n	Hatched	
5/5/2020	C25-2020	Coot	B	4	n	Unknown	
5/7/2020	C26-2020	Coot	B	6	n	Unknown	
5/21/2020	C27-2020	Coot	B	5	n	Unknown	
6/4/2020	C28-2020	Coot	B	6	n	Hatched	
8/6/2020	C29-2020	Coot	A	5	y	Hatched	
8/20/2020	C30-2020	Coot	B	4	n	Hatched	
8/20/2020	C31-2020	Coot	B	8	y	Hatched	
8/20/2020	C32-2020	Coot	B	4	n	Hatched	
8/20/2020	C33-2020	Coot	B	2	n	Hatched	

10/29/2020	C34-2020	Coot	A	5	y	Hatched	
11/12/2020	C35-2020	Coot	B	7	y	Hatched	
2/6/2020	G01-2020	Gallinule	D	4	y	Failed	Flooded
3/11/2020	G02-2020	Gallinule	A	4	y	Hatched	
3/18/2020	G03-2020	Gallinule	D	6	y	Hatched	
4/9/2020	G04-2020	Gallinule	B	6	n	Unknown	
4/9/2020	G05-2020	Gallinule	B	5	n	Unknown	
4/9/2020	G06-2020	Gallinule	A	4	n	Hatched	
4/9/2020	G07-2020	Gallinule	A	4	n	Unknown	
4/9/2020	G08-2020	Gallinule	A	5	n	Unknown	
4/9/2020	G09-2020	Gallinule	A	4	n	Unknown	
4/9/2020	G10-2020	Gallinule	A	3	n	Unknown	
4/9/2020	G11-2020	Gallinule	A	3	n	Unknown	
4/9/2020	G12-2020	Gallinule	B	4	n	Unknown	
4/9/2020	G13-2020	Gallinule	B	6	n	Hatched	
4/9/2020	G14-2020	Gallinule	B	6	n	Unknown	
4/9/2020	G15-2020	Gallinule	B	4	n	Unknown	
4/9/2020	G16-2020	Gallinule	B	5	n	Unknown	
5/7/2020	G17-2020	Gallinule	A	5	n	Failed	Abandoned
5/7/2020	G18-2020	Gallinule	B	5	n	Unknown	
5/7/2020	G19-2020	Gallinule	B	0	n	Hatched	
5/7/2020	G20-2020	Gallinule	D	2	n	Hatched	
5/21/2020	G21-2020	Gallinule	A	1	n	Unknown	
8/6/2020	G22-2020	Gallinule	B	3	y	Hatched	
8/20/2020	G23-2020	Gallinule	A	5	y	Failed	Abandoned
8/20/2020	G24-2020	Gallinule	C	6	y	Failed	Mongoose
8/20/2020	G25-2020	Gallinule	C	5	y	Hatched	
11/12/2020	G26-2020	Gallinule	C	5	y	Hatched	
4/14/2020	S01-2020	Stilt	B	4	y	Hatched	
4/23/2020	S02-2020	Stilt	A	4	y	Hatched	
4/23/2020	S03-2020	Stilt	B	3	n	Unknown	
4/23/2020	S04-2020	Stilt	C	4	n	Unknown	
4/23/2020	S05-2020	Stilt	C	4	n	Hatched	
4/23/2020	S06-2020	Stilt	C	4	n	Unknown	
4/23/2020	S07-2020	Stilt	C	4	n	Unknown	
4/23/2020	S08-2020	Stilt	C	4	n	Hatched	
4/23/2020	S09-2020	Stilt	C	4	n	Unknown	
4/23/2020	S10-2020	Stilt	C	4	n	Hatched	
4/23/2020	S11-2020	Stilt	C	3	n	Hatched	
4/23/2020	S12-2020	Stilt	A	4	y	Hatched	
5/7/2020	S13-2020	Stilt	A	4	n	Unknown	
5/7/2020	S14-2020	Stilt	B	4	n	Unknown	
5/7/2020	S15-2020	Stilt	C	4	n	Unknown	
5/7/2020	S16-2020	Stilt	C	3	n	Unknown	

5/7/2020	S17-2020	Stilt	C	3	n	Unknown	
5/7/2020	S18-2020	Stilt	C	4	n	Hatched	
5/7/2020	S19-2020	Stilt	C	4	y	Failed	Abandoned
5/21/2020	S20-2020	Stilt	A	1	n	Failed	Abandoned
5/21/2020	S21-2020	Stilt	A	4	y	Failed	Abandoned
5/21/2020	S22-2020	Stilt	B	3	y	Hatched	
5/21/2020	S23-2020	Stilt	B	4	y	Hatched	
5/21/2020	S24-2020	Stilt	B	1	n	Unknown	
5/21/2020	S25-2020	Stilt	C	4	n	Unknown	
5/21/2020	S26-2020	Stilt	C	4	n	Unknown	
5/21/2020	S27-2020	Stilt	D	4	n	Unknown	
6/4/2020	S28-2020	Stilt	B	4	y	Hatched	
6/4/2020	S29-2020	Stilt	B	4	n	Unknown	
6/4/2020	S30-2020	Stilt	B	4	y	Failed	Gallinule
6/4/2020	S31-2020	Stilt	C	4	n	Unknown	
6/4/2020	S32-2020	Stilt	C	1	n	Unknown	
6/4/2020	S33-2020	Stilt	C	4	n	Unknown	
6/4/2020	S34-2020	Stilt	D	4	n	Unknown	
6/18/2020	S35-2020	Stilt	C	4	y	Failed	Abandoned

Table 3. The number of observed chicks, broods, fledglings, percent fledging success, and fledglings per brood for Hawaiian Coot, Hawaiian Gallinule, and Hawaiian Stilt in 2020 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		
2007	2	1	50%	—	41	36	73%	—	16	13	81%	—
2008	—	5	—	—	35	33	73%	—	13	10	8%	—
2009	5	4	67%	—	52	50	85%	—	16	16	76%	—
2010	11	10	82%	—	56	44	88%	—	9	6	67%	—
2011	14	9	64%	—	33	30	89%	—	4	2	50%	—
2012	13	8	—	—	31	20	77%	—	5	4	80%	—
2013	6	2	50%	—	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	97%	—	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	46 (17)	30	68%	1.8	33 (18)	24	73%	1.3
2021									37 (10)	10	27%	1.0
Total	**151 (31)**	**83**	**64%**	**1.0**	**726 (44)**	**543**	**75%**	**2.0**	**274 (32)**	**174**	**64%**	**1.4**

Table 4. Summary of coot (C), gallinule (G), and stilt (S) *nest parameters* (%HS = % hatching success) and *nest failures*. We collected data at Hāmākua Marsh, Kailua, Hawaiʻi, USA as determined by passive infrared cameras and manual nest surveys in 2020.

		C (*n*=36)	G (*n*=26)	S (*n*=35)	Total [a]
Camera (*n* = 31)					
Nest parameters					
	Hatched (%HS)	7 (64)	5 (63) [b]	6 (60)	18
	Clutch size	4.8	4.8	3.9	
Nest failures					
Predator	Hawaiian Common Gallinule (*Gallinula galeata sandvicensis*)			1	1
	Small Indian mongoose (*Herpestes javanicus*)		1 [c]		1
Other failure	Abandoned	1 [d]	1 [d]	3 [e]	5
	Flooded	3	1		4
Unknown		2 [f]			2
No camera (*n* = 66)					
Nest parameters					
	Hatched (%HS)	10 (77)	4 (80)	5 (83)	19
	Clutch size	4.8	4.0	3.5	
Nest failures					
Other failure	Abandoned	1	1	1	3
	Flooded	2			2
Unknown		10	13	19	42

[a] Sum of independent hatching and nest failure events.
[b] Partial depredation on one nest.
[c] Assumed predator presence caused abandonment and eventual total depredation of nest.
[d] Abandoned for unknown reason.
[e] Two abandoned for unknown reasons and one abandoned due to conspecific skirmish.
[f] Cameras placed too late to determine fate of nests.

Table 5. Reproductive metrics for coot (HACO; *n* = 36), gallinule (HAGA; *n* = 26), and stilt (HAST; *n* = 35) in Hāmākua Marsh, Kailua, Hawaiʻi, 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	72%	65%	51%	73%	88%	72%	53%	58%	37%

Table 6. Predators captured by month at Hāmākua Marsh, Kailua, Hawaiʻi, USA, 2020.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mongoose	6	8	6	0	0	3	9	2	1	5	2	1	43
Cat	0	0	0	0	0	0	0	0	0	0	0	0	0
Rat	0	0	0	0	0	2	1	3	4	9	8	10	38
Cane toad	0	0	0	0	0	0	0	2	0	1	3	2	8