From:	Kilbride, Kevin
To:	Stenvall, Charlie
Cc:	Flanders, Bridgette; Seto, Nanette; BrownScott, Jennifer; Garrett, Alice
Subject:	Re: [EXTERNAL] SHR2017-00011
Date:	Thursday, January 16, 2020 8:20:33 AM
Attachments:	Ashe Hanabusa Response Letter.pdf Fencing Project Final Report.pdf
Importance:	High

Hi, Charlie:

As we discussed, this situation is similar in a number of ways to the taro fencing pilot at Hanalei NWR (2013). We established an agreement with Oregon State Univ (Bruce Dugger) to conduct a study that was done in conjunction with the pilot to address specific questions about impacts. Ultimately, the 1 yr pilot ended and fencing was no longer allowed on the refuge after the Director issued the attached letter (it's suitable for framing in my opinion as it was a monumental decision on behalf of the resource). As described in the letter, the monitoring documented impacts of fencing on endangered waterbirds (see attached report) that played a prominent/key role in the Director's decision to not allow fencing of taro to continue on the refuge at the conclusion of the pilot.

Therefore, I would suggest an independent expert handle the "disturbance" monitoring to assess impacts for Phase 1 aquaculture pilot. Also, the on-going water quality monitoring should be evaluated for its ability to evaluate potential project-specific impacts of Phase 1 to water quality. Keep in mind the Improvement Act states maintaining adequate water quantity and water quality to achieve the Refuge System Mission and refuge purposes; any impacts to water quality on the project site would likely affect the refuge. For the report, it's my understanding DOH is currently conducting baywide water quality monitoring, but I would suggest a risk assessment-based monitoring approach specifically tailored for the project may be needed given the level of scrutiny and the need for high scientific rigor.

Kevin Kilbride
US Fish and Wildlife Service
I&M Coordinator
Columbia Pacific Northwest (R9)&Pacific Islands (R12)
Branch of Refuge Biology
911 NE 11th Avenue
Portland, OR 97232
(503) 231-6176 (Phone)
(503) 347-0292 (Cell)

On Mon, Jan 13, 2020 at 2:50 PM Stenvall, Charlie <charlie_stenvall@fws.gov> wrote:

> The decision from the Hearing Examiner on the Jamestown S'Kallam oyster farm within Dungeness NWR has been issued. The specific decision can be found on pages 44 - 46. It isn't what we had hoped but assuming the Tribe can get the ACOE and WDNR permit as well as meet the other conditions, they will have the opportunity to farm five acres for five years within Dungeness NWR as a first phase. In the conditions, the Examiner states the Tribe must enter into a MOU with the Olympic Peninsula Audubon Society and USFWS to monitor the impacts of this action on the Refuge. We will have a small window in which, if there are impacts, be able to document and quantify them. Jennifer and Sue are going to need some help on what protocols will give us the data and information we need to evaluate that either prove or ally our concerns. I suspect there may be differences in what the Tribe would want to do for this level of monitoring and therefore help from Mig Birds and the Regional Refuge biology program will be invaluable. Jennifer is going to be reaching out to ACOE and WDNR and get a sense on how they see their processes going and if they are going to make the MOU a condition for their permit, should they decide to permit this

activity. This email is just a heads up that Jennifer will reach out once the timing and effort to develop an MOU are clear. Hopefully we can rally and assist them when the time comes.

Charlie

---------- Forwarded message ---------
From: **BrownScott, Jennifer** <jennifer_brownscott@fws.gov>
Date: Mon, Jan 13, 2020 at 8:48 AM
Subject: Fwd: [EXTERNAL] SHR2017-00011
To: Stenvall, Charlie <charlie_stenvall@fws.gov>

FYI. Haven't had time to look at this in depth yet. But it appears that Phase I has been approved with conditions. One of the conditions looks like we are required by the County to enter into an MOU with the Tribe for monitoring and analysis of potential impacts (#9, pg 46). Any thoughts on who could assist us with creating a scientifically defensible disturbance protocol? Analysis of impacts from Phase I would be used to inform potential approval of Phase II.

It would seem to make sense to wait for the ACE decision before creating an MOU or working through the type of surveys and analysis that should be completed. Otherwise, we could be spending a lot of time without knowing if the use will gain final approval. However, the Tribe may want to start discussions right away.

Happy Monday!

-jennifer

____
Jennifer Brown-Scott
Refuge Manager
Washington Maritime NWRC
715 Holgerson Rd
Sequim, WA 98382
office: (360) 457-8451 ext.22
fax: (360) 457-9778

~~Dungeness NWR~Protection Island NWR~San Juan Islands NWR~~
~~Copalis NWR~Flattery Rocks NWR~Quillayute Needles NWR~~

---------- Forwarded message ---------
From: **Breitbach, Tami** <TBreitbach@co.clallam.wa.us>
Date: Mon, Jan 13, 2020 at 8:10 AM
Subject: [EXTERNAL] SHR2017-00011
To: Breitbach, Tami <TBreitbach@co.clallam.wa.us>
Cc: Ballard, Greg <gballard@co.clallam.wa.us>

Please find attached the Notice of Decision, and Findings of Fact, Conclusions of Law and Decision regarding the above-referenced proposal.

<<NOTICE OF DECISION - JAMESTOWN SHR2017-00011.docx>>

<<Clallam - Jamestown S'Klallam Oyster Farm SSDP-SCUP.pdf>>

Regards,

Tami Breitbach

Administrative Specialist II

Clallam County

Department of Community Development

223 East Fourth Street, Suite 5

Port Angeles, WA 98362

(360) 417-2277

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Washington, D.C. 20240

JUL 15 2013

The Honorable Colleen W. Hanabusa
House of Representatives
Washington, D.C. 20515

Dear Representative Hanabusa:

Thank you for your letter of May 21, 2013, regarding the efforts of the U.S. Fish and Wildlife Service (Service) to support continued taro farming on Hanalei National Wildlife Refuge (Refuge). It is important to the Service that we work to the maximum degree practical to strike a balance between sustaining the existing taro farms and protecting the endangered Hawaiian birds on the Refuge.

As noted in your letter, the experimental Biological Opinion (BiOp) that was written to allow limited use of fencing around the taro farms expired on May 31, 2013. The BiOp was intended to provide coverage for limited impacts that resulted from fencing erected to protect the taro farms from depredation. However, only a small subset of taro permittees within the Refuge's boundaries erected fences (and thus benefitted from the BiOp) and during the time fencing was in place, there were impacts to listed species as a result of the project.

Given the impacts to listed species and the limited utility of the BiOp to the taro permittees, it is clear that extending or developing a new BiOp will not resolve the challenges at the Refuge. Consequently, the Service will not be extending or preparing a new BiOp to address taro farming. Instead, we will use our resources to work with the taro permittees to pursue long-term solutions to the challenges at the Refuge that do not harm endangered birds and other wildlife and do not place undue financial burdens on the taro permittees or the Refuge.

The BiOp calls for data collected associated with this project to be analyzed through a separate effects monitoring study. The Service anticipates that the study will be helpful in minimizing future impacts to listed species and a draft monitoring report is anticipated by the end of calendar year 2013. We will share the results of the effects monitoring study as soon as they become available.

Although the Service will not be extending or preparing a new BiOp, we are actively pursuing other long-term solutions. The Service has committed $56,000, through the National Wildlife Refuge System's Natural Resource Program Center, to conduct a monitoring study that will investigate waterbird use of food sources in taro cultivation ponds. A scope of work, to articulate the details of this monitoring study, is being developed. To fully understand waterbird use of food sources, the study will include ponds planted only with taro, as well ponds planted with a mixture of taro and other non-taro plants. The study would be conducted from January 2014 to May 2014. Providing additional "non-taro food sources" in and around the existing taro farms may prove to be an alternative solution.

This proposed monitoring is consistent with the management direction in the Refuge's draft Comprehensive Conservation Plan (CCP) and the current compatibility determination stipulations for taro permittees to maintain 25-50 percent non-taro plants in 50 percent of the taro cultivation ponds. Part of the outreach associated with this monitoring study includes relaying the results of the taro fencing experiment conducted last year, and discussing the monitoring approach noted above with the Refuge's taro permittees at their annual September meeting with the staff from the Refuge. We are also proposing to work with a professional mediator in order to effectively engage in discussions between the Service and the permittees about future proposed monitoring direction, and how information derived from the monitoring study could be used to formulate long term taro cultivation strategies on the Refuge.

The Refuge was established under the Endangered Species Act to conserve five endangered water birds that rely on the Hanalei Valley for nesting and feeding habitat: the koloa maoli (Hawaiian duck), the 'alae ke'oke'o (Hawaiian coot), the 'alae'ula (Hawaiian moorhen), the ae'o (Hawaiian stilt), and the nēnē (Hawaiian goose). At the time the Refuge was established, taro farming was allowed to continue as an alternative form of management to benefit the birds. As long as the taro farming operations remain beneficial to the birds, we will be able to continue to allow the use. This is our goal.

If you have any further questions, please don't hesitate to contact me personally or have your staff contact Ms. Robyn Thorson, the Service's Pacific Northwest Regional Director at 503-231-6118.

Sincerely,

DIRECTOR

Quantifying the effects of taro fencing on endangered waterbirds and taro plants at Hanalei National Wildlife Refuge, Kauaʻi.

Submitted by:

Bruce D. Dugger
Julie K. Unfried

and

Christopher P. Malachowski

Department of Fisheries and Wildlife
Oregon State University
104 Nash Hall
Corvallis, OR 97331
Phone: 541-737-2465
E-mail: bruce.dugger@oregonstate.edu

5 February 2015

EXECUTIVE SUMMARY

Complaints about suspected reduced crop yields by endangered waterbirds resulted in two of nine permittee farmers at Hanalei National Wildlife Refuge, Kaua‘i being allowed to temporarily place fences around three refuge taro patches (called lo‘i) during March – May in 2013. This fencing, which was authorized under a short-term Biological Opinion (BO) written by the U.S. Fish and Wildlife Service, stipulated monitoring be conducted to assess for possible negative impacts (take) of fences described in the BO to five federally endangered waterbird species (Hawaiian coot, Hawaiian moorhen, Hawaiian goose, Hawaiian stilt, and Hawaiian duck). This report summarizes the results for much of the take monitoring required by the BO. Additional data collected by USFWS staff, volunteers, and Oregon State University contractors during daily compliance check surveys will be reported separately. Besides the BO, the questions and objectives in this report were expanded as a result of meetings with refuge staff and the permittee taro farmers. In this report, we addressed the following four monitoring questions:

1. *Do fences around taro lo‘i cause injury, death or other negative impacts to endangered waterbirds?*
2. *Does fencing reduce the use of taro lo‘i by waterbirds?*
3. *How do waterbirds use young taro lo‘i, and does their behavior differ between fenced and unfenced lo‘i?*
4. *Do fences improve the survival and health of young taro plants?*

Temporary fences were installed around the perimeter of three recently planted lo‘i. Each fenced lo‘i was paired with a control (unfenced) lo‘i of similar age that was cultivated by the same permittee farmer. For some questions, it was also appropriate to collect data from additional lo‘i on the Refuge. We used remote cameras placed along the fence lines to quantify the types and frequency of interactions between waterbirds and taro fences and to look for any instances of injury or mortality. We conducted waterbird surveys and behavioral observations to compare bird abundance and behavior between fenced and unfenced lo‘i as well as describe and quantify how waterbirds interacted with young taro plants. Finally, we collected data on taro plants to determine if fences influenced plant survival and growth as indicators of potential depredation and reduced crop yield. Because the sample size of fenced lo‘i available for study was small, we recommend caution when drawing inference from our results. That said, the

results do provide insight about the questions addressed in this report and can contribute to further understanding about taro cultivation as a refuge management activity at the Refuge in support of endangered waterbird recovery.

Conclusions include:

- Fences created obstacles that resulted in collisions for waterbirds. The frequency of high impact collisions was highest for moorhens. We detected no injury or mortality of endangered waterbirds as a result of a fence collision. Observational methods (cameras) could not detect internal injuries or minor external injuries or death once the bird exited the camera view plane. We extrapolated that the number of collisions between waterbirds and fences was likely considerable. However, we could not quantify the effect of these fence interactions on individual birds or waterbird vital rates, so we cannot quantify if these fence interactions influenced the population dynamics of any waterbird species.
- The ability of fences to exclude waterbirds from loʻi varied by species. There were no differences in abundance between fenced and unfenced loʻi for Hawaiian stilt, Hawaiian moorhen, or Hawaiian duck. Hawaiian coots were less abundant in fenced than unfenced loʻi, which indicated fences reduce habitat availability most for coots. Nēnē were not seen in loʻi during diurnal surveys, so the effectiveness of fences for excluding them is not clear.
- There was no difference in waterbird behavior during the day between fenced and unfenced loʻi for any species, which suggested there was no impact of fences on behavior within loʻi. In addition, coots and moorhens spent little time each day interacting with taro plants (4.5% ± 1.1% for moorhen and 3.6 ± 0.9% for coots), which translated to 32.4 minutes for moorhens and 25.9 minutes for coots during a 12-hour daylight period. Of that, time spent feeding on taro leaves or stems was approximately 3 minutes for coots and 4 minutes for moorhens.
- Survival of young taro plants was higher in fenced compared with unfenced loʻi. However, all measures of plant growth were similar between fenced and unfenced loʻi for those plants that did survive. We did not collect data to determine if harvest yields were different between fenced and unfenced loʻi.

TABLE OF CONTENTS

INTRODUCTION

During July 2012, the U. S. Fish and Wildlife Service approved a short-term Biological Opinion (BO) that authorized the installation of temporary fences at Hanalei National Wildlife Refuge (hereafter the Refuge). The fencing project was a temporary action in response to concerns by 4 of the 9 permittee farmers who reported substantial taro (kalo; *Colocasia esculenta*) crop losses that they attributed to endangered waterbirds. The BO stipulated that monitoring would be conducted to check compliance of fence integrity and document incidental take. Additionally, monitoring would be conducted to help resolve questions regarding the effects of fencing on endangered waterbirds and taro (USFWS Final BO, pg 5). This report outlines the methods and presents the results of a project for all monitoring activities except those related to compliance.

Five species of endangered Hawaiian waterbirds occur on the Refuge: Hawaiian Goose (Nēnē; *Branta sandvicensis*; hereafter called nēnē), Hawaiian duck (Koloa maoli; *Anas wyvilliana*; hereafter called koloa), Hawaiian coot (ʻAlaekeʻokeʻo; *Fulica alai*; hereafter called coot), Hawaiian moorhen (ʻAlae ʻula; *Gallinula chloropus sandvicensis*; hereafter called moorhen), and Hawaiian stilt (Aeʻo; *Himantopus mexicanus knudseni*; hereafter called stilt). Collectively, these species are hereafter called waterbirds. The availability of suitable wetland habitat is a constraint on recovery for all waterbirds except nēnē (USFWS 2011). Further, Refuge wetlands are identified as "core habitat" essential for recovery of the four wetland-dependent waterbird species (USFWS 2011), and management on the Refuge is targeted at increasing their population sizes.

The BO determination was that placing fences around taro loʻi (a loʻi is analogous to a rice paddy) would likely result in injury or mortality to waterbirds that collide with the fence, fences would negatively influence the behavior of birds in and around fenced loʻi increasing stress levels on birds, and that fences would exclude birds from using loʻi during certain stages in their life cycles. The objectives in this report flow from impacts identified in the BO and evolved from meetings with USFWS staff and the permittee taro farmers on the Refuge. Based on stipulations in the BO and conversations with USFWS staff and the taro farmers, we developed a study to monitor bird abundance and behavior in taro loʻi when plants were <100 days old and to compare abundance and behavior in fenced and unfenced loʻi. We also monitored plant survival and growth and compared these metrics between fenced and unfenced loʻi to evaluate potential effects of fencing on plants via excluding or limiting access by waterbirds.

Questions and objectives

1. Do fences around taro loʻi cause injury, death or other negative impacts to endangered waterbirds?

Fences create a barrier that could physically harm birds that collide with or become entangled in the fence. Moorhen and coot are easily startled, and the initial response of both species is often to lower their head and run or flush (fly) towards cover (Pratt and Brisbin 2002, Bannor and Kiviat 2002). Taro permittees and Refuge staff have observed moorhen running into installed fences, and in one instance a moorhen was observed getting its leg entangled in a fence (USFWS BO, July 2012). Quantifying the frequency and intensity of bird interactions with fences is one method for studying the impact of fences on waterbirds. Fence perimeter surveys and camera surveillance of fences provide a means to identify and quantify this impact. More generally, birds may interact with fences in a variety of ways representing different levels of intensity, and cataloging and quantifying the types of interactions birds have with fences will provide information for a more complete understanding of how fences may affect waterbird health and survival.

<u>Objective 1:</u> Describe and quantify the types of interactions that birds have with fences to provide an alternate measure of impact beyond direct mortality and injury.

2. Does fencing reduce the use of taro loʻi by waterbirds?

Taro provides habitat for all species of endangered waterbirds on the Refuge during all phases of their annual cycle (Gee 2007, USFWS BO 2012, Malachowski 2013). Consequently, if fences exclude birds from loʻi they prevent access to food, cover, nesting and brood rearing areas. This reduces the overall capacity of the Refuge to accomplish its primary purpose by decreasing the amount of habitat available to meet the daily habitat needs of waterbirds. Because the waterbird species at the Refuge are known to possess different behavioral characteristics (e.g., willingness to climb), fences may not affect each species' ability to enter and exit a fenced loʻi similarly. A comparison of waterbird abundance in fenced and unfenced loʻi will provide one measure of fencing impacts on birds by measuring the effectiveness of fences at reducing waterbird use of lo‘i. Comparing abundance will also provide a measure of fence effectiveness for excluding waterbirds, which is the reason for fence installation.

Objective 2: Compare abundance of waterbirds in fenced and unfenced lo‘i.

3. *How do waterbirds use young taro lo‘i and does their behavior differ between fenced and unfenced lo‘i?*

It is unlikely that fences will completely exclude waterbirds from lo‘i; thus, one additional concern of the Refuge staff is that fences may impact the behavior of birds that do enter fenced lo‘i. There is no published data describing how waterbirds use young taro lo‘i. While some data are available (Gee 2007, Malachowski and Dugger unpubl. data), they are not sufficient to inform management issues and were not collected under the experimental conditions necessary to assess the impact of fences. Thus, characterizing and quantifying how waterbirds use young taro lo‘i would help develop a mechanistic framework for understanding how fences might impact waterbirds and comparing behavior of birds using fenced and unfenced lo‘i would provide one method for measuring the impact of fences on waterbirds. While there might be many possible behavioral changes associated with fences, the most direct comparison would be of time spent foraging because this behavior directly relates to food, which influences the capacity of birds to meet their daily energy needs and complete life cycle events; it is related to habitat quality, which is a specific habitat management target for the Refuge. More generally, there was interest in characterizing the types and frequency of interactions that waterbirds have with taro plants to help develop a better understanding of this important relationship. Farmers expressed concern that coot, moorhen, and nēnē were most responsible for damage to taro plants. Consequently, we created the following two objectives:

Objective 3: Characterize and quantify waterbird behavior in young taro lo‘i and compare behavior of waterbirds in fenced and unfenced lo‘i.

Objective 4: Characterize how waterbirds interact with taro plants and their relative frequency of occurrence.

4. *Do fences improve the survival and health of young taro plants?*

This fencing trial provided an opportunity to collect data on plant performance and compare performance between fenced and unfenced lo‘i. Based on previous unauthorized fencing activities in the 1990s, refuge taro farmers believe fencing reduces waterbird use of a lo‘i, which results in improved plant performance. A detailed test of this idea would require directly measuring taro yield at the time of harvest. We were unable to compare yield between fenced and unfenced lo‘i because the duration of the fencing experiment. Instead, we compared more proximate measures for yield including plant survival and growth.

<u>Objective 5:</u> Measure and compare plant survival and indices of plant health between fenced and unfenced lo‘i.

The remainder of this report is organized around these questions and objectives. This report was prepared to present results that can aid in making management decisions or informing future conversations between the USFWS and taro farmers.

STUDY AREA

Monitoring was conducted at Hanalei National Wildlife Refuge (the Refuge) on the island of Kauaʻi. Data for comparisons of abundance and behavior between birds in fenced and unfenced loʻi were collected from six loʻi cultivated by two permittee farmers on the Refuge (Fig. 1). For more general questions about bird behavior in taro and use of taro, the sample loʻi were drawn from all taro loʻi containing plants less than three months of age.

Fences were installed to minimize gaps between the bottom of the fence and the loʻi dike and to minimize any sharp edges or projections that might injure birds. The construction details for all fences were similar and outlined in the BO. Language in the BO specified that "*fencing material would be 3-4 feet tall, one-inch mesh poultry fencing (i.e., chicken wire) anchored with 5-6 foot lengths of ½ to ¾ inch rebar placed 5-25 feet apart (close enough to keep fence from sagging). When needed, the dike would be mowed before installation so fence material is flush with dike and there would be no or minimal gaps between dike and fence. The fence would be installed 8-12 inches from edge of dike and water. The fence installation and breakdown would be conducted by 1-3 people (~2 hours for a ½-acre loʻi; ~4 hours for a ½-acre loʻi including preparation time). Ends of fencing material would overlap 1-3 feet, and rebar would be woven in fence and pushed or hammered into ground."* (USFWS 2012).

To provide examples of what a taro lo ʻi looks like and how conditions changed over time, particularly during data collection activities, we took a series of photos from a fixed location at each loʻi (Appendix A). Additionally, on 2 January 2014, we took another set of photos for each loʻi seven months after fences had been removed (Appendix B) as examples of how loʻi conditions change with taro age.

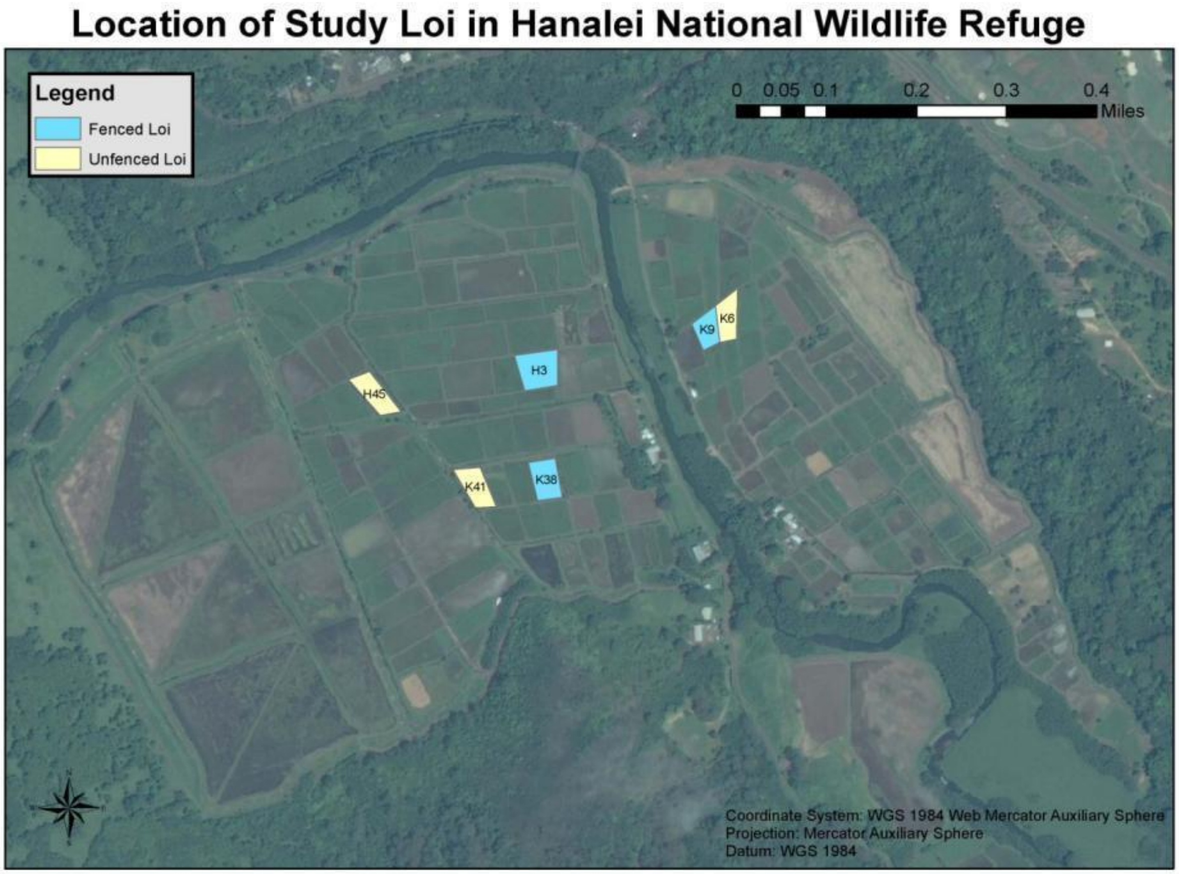


Figure 1. Location of fenced and unfenced taro lo‘i included in the study of fencing impacts on waterbirds. Each fenced lo‘i was matched to an unpaired lo‘i of similar age farmed by the same permittee farmer (K6/K9, K38/K41, H3/H45).

METHODS

Study Design

The experiment was a paired plot design and one replicate consisted of a treatment (fenced) and control (unfenced) lo‘i. Three lo‘i (H3, K9 and K38) were included in the treatment group and three lo‘i (H45, K6, and K41) served as the control group. Treatment lo‘i had a fence installed around their perimeter after completion of young taro planting. Each fenced lo‘i was paired with an unfenced lo‘i that served as a control. Control lo‘i were of similar age and cultivated by the same farmer as the treatment lo‘i (Fig. 1). This provided three replicated pairs of lo‘i for our study (H3/H45, K6/K9, and K38/K41). Taro varieties planted in individual lo‘i included Maui Lehua, Kaua‘i Lehua, Bun-long, and Lehua Ho‘ohua (Table 1).

Data Collection

1. Do fences around taro lo‘i cause injury, death or other negative impacts to endangered waterbirds?

<u>Objective 1: Describe and quantify the types of interactions that birds have with fences to provide an alternate measure of impact beyond direct mortality and injury.</u>

We used cameras placed along the fence perimeter to describe and quantify the types of interactions birds had with fences. The camera took a photo once every second during deployment. We used stakes placed at intervals along the fence or support stakes used to hold the fence to determine the effective distance that cameras could be used to monitor bird behavior along the fence and recorded that distance for each observation session. Camera placement was determined by first selecting a lo‘i and one of the four sides of the lo‘i for monitoring. Selections continued, without replacement, until all sides of each lo‘i had been sampled, and then the process repeated. We were unable to use cameras effectively at night as the effective range of the cameras were short. Thus, our results reflect diurnal interactions including crepuscular periods during both morning and evening.

We downloaded each day’s set of images and selected up to three, one-hour blocks of time each day to view and transcribe interactions depicted on film into a database. Viewing effort was equally distributed across the three daily time periods (defined in objective 2a below) and across hours within each time period. We recorded encounters with the fence as described in Table 2. Probing was defined as birds pacing along the fence, sometimes back and forth, in an apparent effort to cross the fence boundary. In some cases it involved pecking at the fence. Although we differentiated between interactions when birds were on the inside or outside of the fence during data transcription, we combined these categories for data summary and analysis, resulting in 5 categories (probe, climb fence, crawl under fence, run into fence, and fly into fence). The types of encounters could be considered as expressing a range of intensity with low intensity interactions (e.g., Probe), intermediate intensity interactions (e.g., climb or crawl), and high intensity (e.g., run into or fly into). Encounter data for each 1 h block of time was standardized to the number of occurrences per 12 h of daylight per 100 m of fence. When sample sizes permitted, we used a general linear model to look for trends in specific behaviors with time period and time since the installation of the fence. A decline in one or more activities (e.g., probing the fence) might indicate that birds acclimated to fences over time.

2. Does fencing reduce the use of taro lo'i by waterbirds?

<u>Objective 2a: Compare abundance of waterbirds in paired fenced and unfenced lo'i during the day.</u>

We conducted surveys of bird abundance during the day in all experimental lo'i using a 20-60x spotting scope from the refuge overlook site on state hwy 560 (Kuhio Hwy; 22°12'45.62" N lat, 159°28'32.80" W long). Birds in the young lo'i were easily observable, and the remote location avoided disturbances that might affect bird behavior. For each species, data were reported as the number of adults, nests, and broods present. Only birds within the lo'i (i.e., not on the adjacent dike) were included in counts. Surveys were conducted during three time periods each week defined as early (0600-1000), middle (1001-1400), and late (1401-1900) day.

<u>Objective 2b: Compare abundance of waterbirds in paired fenced and unfenced lo'i at night.</u>

Nocturnal surveys of waterbirds in fenced and unfenced lo'i were conducted using a night vision scope from an elevated blind positioned near each pair of lo'i. Nocturnal surveys began no earlier than one half hour after sunset and were completed no later than one half hour before sunrise. The observer waited at least five minutes after arriving at the blind before counting to minimize effects of observer arrival. In addition to plumage characteristics, we used size, shape, and behavioral cues to identify individuals to species. However, identification to species at night was not always possible; discriminating between coot and moorhen could be difficult. Therefore, we created a combined coot/moorhen category when separating those two species was not possible; all other uncertainties were recorded as unknown. As with diurnal counts, only birds within the loʻi (i.e., not on the adjacent dike) were included in counts.

When possible, data for objective 2a and 2b were analyzed two ways. First, a Likelihood Ratio Chi-square test was used to compare waterbird frequency of occurrence during surveys between fenced and unfenced loʻi. This initial analysis simplified the count data into a binomial presence/absence metric for each survey, and is one way to consider data where zeroes are common in surveys. That analysis was conducted separately for each daily time period. Second, all abundance data were log transformed to normalize distributions and then a general linear mixed model analysis was conducted to compare mean bird abundance between fenced and unfenced loʻi. Status (fenced or unfenced) and time period were fixed effects while survey week and loʻi were random effects. Including week and loʻi as random effects controlled for the possibility that repeated surveys in each loʻi were not independent across space and time. We had fewer nocturnal surveys conducted for only two pairs of the replicate loʻi (K38/41, H3/H45). We compared mean abundance between fenced and unfenced loʻi using a general linear mixed model with individual loʻi included as random variable.

3. How do waterbirds use young taro loʻi and does their behavior differ between fenced and unfenced loʻi?

<u>Objective 3: Characterize and quantify waterbird behavior in young taro loʻi and compare behavior of waterbirds in fenced and unfenced loʻi.</u>

We used instantaneous focal sampling procedures (Altmann 1974) to quantify time-activity budgets of waterbirds in taro loʻi less than 100 day old and compare behavior between birds in fenced and unfenced loʻi. Moorhens and coots were the focus of work for objective 3 and 4. Geese were generally not present in loʻi during the day, and the number of koloa and stilt available for observation were too low to permit a meaningful analysis.

Observations were made from blinds supported on towers that had been erected near the study loʻi. Each loʻi on the Refuge was classified as treatment, control, or other. Treatment and control loʻi were those used for the fencing experiment; whereas, loʻi classified as “other” were lo‘i with plants less than 100 days old that were not included in the fencing impact experiment. Upon arrival to an observation tower, observers waited at least five minutes before sampling began to minimize observer-influenced behavior. Focal individuals were randomly selected from birds inside the lo‘i using a random number chart, based on the total number of individuals present for that species. Birds were counted from left to right until the randomly selected number was reached.

Individual birds were observed for a minimum of 5 minutes and a maximum of 15 minutes, and behaviors were recorded at 10-second intervals as one of six activities: foraging, locomotion, maintenance, rest, alert, and social (Table 3; Paulus 1988, Dugger and Petrie 2000, Crook et al. 2009). Importantly, when birds were observed in foraging behavior, we could not always distinguish what they were foraging on. All data were recorded using a digital voice-activated recorder and timer and transcribed by hand. Behavioral surveys were stratified by diurnal time period (defined above) so that sampling was distributed approximately evenly among morning, midday, and afternoon periods. Only one behavioral survey of each species was conducted for each time period in each lo‘i on any single day to ensure independence among samples. If there were no birds present in the first lo‘i visited, we randomly selected another lo‘i to sample.

For analysis, behavior data were converted to proportions of time engaged in each behavior during each focal observation session (Baldassarre et al. 1988). Logit transformations were applied to proportions before analyses to improve homogeneity of variances and meet the assumption of normality (Ramsey and Schafer 2002). Individual focal observation sessions were the sample unit used to determine the relationship between behaviors and the explanatory variables fencing status (fenced vs. not fenced) and species.

We first tested for an effect of fences on behavior for each species. This analysis relied on data collected only in the lo‘i used for the fencing experiment (fenced and unfenced pair). We used factorial multivariate analysis of variance (MANOVA) and Wilks’ lambda test criterion to simultaneously test if behavioral patterns differed between fenced and unfenced lo‘i (Ramsey and Schafer 2002). MANOVA is most appropriate because individual behaviors in a focal observation sample are not independent (i.e., the proportion of time spent in one behavioral activity affects the proportion of time spent in other activities). If MANOVA indicated significant effects of explanatory variables ($P < 0.05$), univariate general linear models were used to further examine the effects on separate behaviors. Second, we conducted a specific analysis to compare time spent foraging between birds in fenced and unfenced lo‘i. Third, we summarized the behaviors for each species using young taro lo‘i in general using the larger data set that included observations on all young lo‘i in the study, and tested for differences in behavioral patterns among species using a MANOVA as described above.

Objective 4: Characterize the ways that waterbirds interacted with taro plants and their relative frequency of occurrence.

Data for this objective were gathered from any unfenced lo‘i less than 3 months of age on the Refuge. The general sampling approach and protocol were similar to Question 3 above with the exception that behaviors were recorded at 1 second intervals rather than 10 second intervals. The more frequent interval increased the likelihood of recording rare behaviors and allowed us to make finer behavioral distinctions (Martin and Bateson 2007). This more intensive behavior session occurred after completion of data collection related to Question 3. Thus, if birds remained in the lo‘i after the initial 15 minute session concluded, we conducted a second session that recorded behavior at 1 second intervals. During this more intensive observation period, we recorded additional details about how waterbirds interacted with taro (Table 4).

As with objective three, individual focal observation sessions were the sample unit for analysis and activity data were converted to percentages of time engaged in each behavior during each focal observation session (Baldassarre et al. 1988). One observation session for coots and two for moorhens with values greater than five standard deviations from the mean were not included in analyses. After logit transforming percent time spent interacting with taro to normalize the data, we used a general linear mixed model to test if time spent interacting with taro was similar between coots and moorhens. For that analysis, species was a fixed effect and lo‘i status (fenced or unfenced) was a random variable. Many individual behaviors were so rare that analysis of each individually was not feasible. To compare behaviors between coots and moorhens, we collapsed several behaviors into broader categories labeled FEED (eat leaf, eat stem), STRUCTURE (perching, standing, walking or swimming over taro), and INTERACT (tug leaf, tug stem, peck at leaf, peck at stem, peck at base of taro plant). The behavior “HEAD UNDER WATER AT BASE OF PLANT” remained separate. The individual behavior HEAD UNDER WATER AT BASE OF PLANT and the behavior category INTERACT reflected the fact that the intent of these behaviors was not clear. For example, when bird was observed tugging or pecking on a leaf, that could represent an attempt to forage on a taro plant, but it also might reflect an attempt to gather nesting material or forage on an invertebrate that was sitting on a taro plant. Similarly, we were unable to determine what the bird was doing when its head was under water near the base of the plant. Birds recorded as FEED were observed handling and swallowing taro.

As with objective 3, we used a factorial multivariate analysis of variance (MANOVA) using Wilks' lambda test criterion to simultaneously evaluate the effects of fencing on time-activity budgets (Ramsey and Schafer 2002). If MANOVA indicated that behaviors differed between species ($P < 0.05$), univariate general linear models were used to further examine differences in behavior between species. If transformations failed to normalize the data and satisfy the equal variance assumption, we used a Kruskal-Wallis test to compare the untransformed percentage of time engaged in the activity by each species (Ramsey and Schafer 2002).

4. *Do fences improve the survival and health of young taro plants?*

<u>Objective 5: Measure and compare plant survival and indices of plant health between fenced and unfenced lo‘i.</u>

At the completion of planting, we sampled a subset of rows in each lo‘i and counted the number of plants in each row. We counted plants for 10% of the rows in each lo‘i and determined the first row to be sampled by randomly selecting a number between one and ten. Once the first row was selected, we systematically sampled every 10th row to evenly distribute the sampling throughout the lo‘i.

At the conclusion of the temporary fencing period, we resampled the rows sampled at the beginning of the study. Sampling dates varied between each member of a pair (fenced/unfenced) so that plant age, defined as the difference between the last day that planting occurred in the lo‘i and the date plants were measured at the end of the experiment, was similar. First, we recounted the number of taro plants in each row. We then collected three measurements on individual taro plants in each row to assess plant health. To determine what plants were sampled, we sequentially numbered each plant in our sample rows and divided by 40 (our desired sample size). For example, if we counted 400 plants and divided by 40, we sampled every 10^{th} plant. If our random number generator produced a value of two, and we would start with the second plant in the first row, and sample every 10^{th} plant thereafter.

For each plant, we measured the number of leaves per plant (Schaffer and O'Hair 1987), leaf area (Lu et al. 2004), and stem length and width at the water/mud interface. Leaf area is a useful index of plant growth and development, which is correlated with dry matter accumulation and taro yield (Jacobs and Chand 1992, Chan et al. 1995). Leaf area was estimated non-destructively by measuring leaf length and/or width (Lu et al. 2004). We used length from the sinus base to the apex of the leaf along the midrib (L_{SA}) as an index of plant area because L_{SA} reliably predicts leaf area in both mature and non-expanded leaves (Lu et al. 2004). After observing considerable variability in leaf shape, we expanded data collection on leaves to include shape (triangle, circle, rectangle, or ellipse) and collected data that would allow us to calculate leaf area using formula for each shape (see below). We measured stem width and length as a surrogate for corm cross sectional area because farmers felt that would be a meaningful measure of plant performance.

The unit for analysis was the individual taro lo‘i (*n* = 3 fenced and 3 unfenced). Taro plant survival was calculated as the total number of plants remaining in the lo‘i at the end of the study divided by the total number counted at the beginning of the study. The basal area of the corm was calculated using the formula for an ellipse, which was the shape that seemed appropriate based on measurements and visual inspection of the plants, and the area of each leaf was calculated using the formula appropriate for the leaf’s designated shape:

1. Triangle area = ½ x base x width
2. Circle area = πr^2, where r equals the radius
3. Rectangle area = length x width
4. Ellipse area = πab, where a and b represented half of the ellipse’s major and minor axes

We used t-tests (Ramsey and Schafer 2002) to compare plant survival, number of leaves per plant, total plant leaf area, and corm basal area between fenced and unfenced lo‘i.

Table 1. Characteristics of individual lo‘i used in the study including the varieties of taro planted in each lo‘i, the date when planting finished, and the date fences were placed around the treatment lo‘i. All dates are 2013.

Lo‘i	**Status**	**Variety planted**	**Finished planting**	**Fencing Date**[a]	**Measurement Date**[b]	**Lo‘i age at end of study**[c]
K6	U	Maui Lehua	9 Feb.	--	24 May	104 d
K9	F	Maui Lehua Kaua‘i Lehua Bun-long	23 Feb.	1 Mar.	6 June	104 d
----------------						
K38	F	Maui Lehua Kaua‘i Lehua	18 Mar.	22 Mar.	27 May	70 d
K41	U	Maui Lehua Kaua‘i Lehua	1 Apr.	--	10 June	70 d

H3	F	Maui Lehua	15 Feb.	19 Mar.	27 May	101 d
H45	U	Maui Lehua Lehua Ho‘ohua	28 Feb.	--	10 June	102 d

[a] The fence around H3 was removed on May 4th. The fence on K9 was removed on May 29th. The fence on K38 was removed on May 30th.

[b] Measurement date varied to equalize the age of plants in each pair of lo‘i when data were collected on plant survival and performance.

[c] Defined as the difference between the last day that planting occurred in the lo‘i and the date that plants were measured at the end of the experiment.

Table 2. Types of behaviors describing how waterbirds interacted with fences at Hanalei National Wildlife Refuge, Kaua‘i, HI, 2013.

Probe fence
Climb over fence to enter lo‘i
Climb over fence to exit lo‘i
Crawl under fence to enter lo‘i
Crawl under fence to exit lo‘i
Run into fence from inside the lo‘i
Run into the fence from outside the lo‘i
Fly into the fence from inside the lo‘i
Fly into the fence from outside the lo‘i

Table 3. Behavioral categories for surveys of endangered waterbirds in fenced and unfenced lo‘i at Hanalei National Wildlife Refuge, Kaua‘i, HI, 2013.

Category	**Behaviors**
Foraging	Dabble, dive, head dip, nibble, peck, probe, scratch, scythe-like sweeps (HAST only), search, snap, up-end
Locomotion	Fly, swim, walk, run, splatter
Maintenance	Preen, bathe, drink, shake, flap, defecate, stretch, scratch
Rest	Loaf, sleep, brood
Alert	Alert posture, head-pump, sky-look, vocalization, bill flick, flush
Social	Courtship, display, intra- and inter-specific interactions

Table 4. List of behaviors used to characterize how Hawaiian coot and Hawaiian moorhen interacted with taro plants at Hanalei National Wildlife Refuge, Kaua‘i, Mar. – May 2013.

Peck at leaf
Peck at stem
Peck at base of taro plant
Eat leaf
Eat stem
Tug leaf
Tug stem
Head under water at the base of a plant
Perch on plant while loafing or resting
Stand on plant while performing maintenance activities
Walk on plant or swim over plant
Up root or knock plant over

RESULTS AND DISCUSSION

Fencing began on 1 March when a fence was installed around K9; the last fence was placed on 22 March. The fences around K9 and K41 were removed on 29 and 30 May, respectively. The fence around H3 was removed early (4 May) because a female koloa with Class 1a ducklings was found within the fenced lo‘i. Lo‘i ranged from 70-104 days old when the fences were removed

1. Do fences around taro lo‘i cause injury, death or other negative impacts to endangered waterbirds?

<u>Objective 1: Describe and quantify the types of interactions that birds have with fences to provide an alternate measure of impact beyond direct mortality and injury.</u>

We captured and viewed 127 hours of photo images (457,200 individual images) collected between 0600 and 1930, which included a total of 372 separate interactions of waterbirds with lo‘i fencing (Table 5). The total includes 76 instances where we could not distinguish species, which in all cases was related to difficulty determining between moorhen or coot. We detected no mortality or obvious injury with remote cameras, but we did record 11 instances of high-intensity interactions (running or flying into fences) for moorhen, 3 for coots, 1 for nēnē, and 3 for moorhen or coot. Additionally, during a visit to move the camera, we startled a moorhen that was inside a fenced lo‘i. That bird ran into the fence and was entangled when its frontal shield got caught on the wire mesh (Appendix C). After a few moments, the bird got free and flew out the other side of the lo‘i. We could see no obvious injury, but we were not able to examine the bird; an inspection of the fence where the bird was caught did not reveal any blood or feathers (JKU personal observation).

Moorhens interacted with fences most frequently and with the broadest range of activities (Table 6). The rate of interaction was highest for low intensity probing followed by intermediate intensity climbing and crawling (Appendix D) and high intensity running or flying into a fence (Appendix E). The rate of probing and climbing the fence did not differ by time period (P’s > 0.10). We hypothesized that the rate of high intensity interactions with the fence might decrease over time as waterbirds acclimated to fences after installation. There were not enough observations of such interactions to test for a trend with date. We were able to test for a linear trend between rate of probing and climbing over the fence for moorhens. There was no trend with time since fencing for either probing ($P = 0.87$) but the rate of fence climbing increased with date since the fence ($P = 0.01$).

There was a difference in how coots and moorhens flew into fences. The occurrence of high intensity interactions with fences by moorhens was most often associated with aggressive interactions among two birds that resulted in one bird being chased into a fence. The bird being chased would run some distance then attempt to escape pursuit by flight, when it would hit the fence. In contrast, coots hit fences by directly flying into them, once while attempting to leave a lo‘i and once by hitting the fence from the outside. Although data on wing loading for coots and moorhens are not available in the literature, linear measurements suggest coots have a higher wing loading than moorhens (Bannor and Kiviat 2002, Brisbane and Mowbray 2002). As a result, coots take longer to achieve flight as they run across the water, which might make them more prone to colliding with fences as they attempt to fly out of small, fenced lo‘i than moorhens.

The single incident of a nēnē colliding with a fence occurred as a flock of birds landed. Most birds landed on the dike outside the fence, but two birds landed inside the fence and one of those hit the fence. All the nēnē proceeded down the dike while periodically foraging, eventually walking out of view.

We detected no direct incidence of injury or mortality for any endangered waterbird species from our camera images, but our methods were not suitable for detecting internal injuries or minor external injuries or determining the status of birds once they moved out of camera range. In a similar fashion, running or flying into fences is not direct confirmation of injury to birds. For behaviors that we did observe, their occurrence rate (Table 6) provides a means of projecting what might happen under a hypothetical three-month fencing scenario. If we consider a lo‘i fenced for 100 days during a period that averages 12 h of daylight, our results project there would be 260 instances of moorhens and 70 instances of coots flying or running into fences for each 100 m of fence installed. Additionally, we could not quantify fence interactions at night, conditions when active birds might be more likely to collide with fences. If birds were active at night (see below) then our projections of interactions based only on daytime observations are an underestimate.

The rate of fence climbing increased with days since fencing for moorhen. We did not make a prediction about this behavior, but two explanations are possible and not mutually exclusive. One, the behavior of individual birds did not change, but the total number of birds on the refuge increased. Two, as individual birds became acclimated to fences they were more willing to climb.

Table 5. The number of specific behaviors recorded by camera traps (between 0600 and 1930) of birds interacting with fences placed around taro lo‘i at Hanalei National Wildlife Refuge, Kaua‘i, March – May 2013. Data collected during daylight hours; *n* = 127 observation periods with a camera totaling 127 h and 457,200 individual images.

	Species[a]					
Behavior	HAMO	HACO	HAST	HAWD	HAGO	RAIL
Probe fence	155	18	2	13	5	29
Climb over fence	74	10	0	0	0	38
Crawl under fence	4	0	0	0	0	6
Run into fence	7	1	0	0	0	0
Fly into the fence	4	2	0	0	1	3

[a] HAMO = Hawaiian moorhen, HACO = Hawaiian coot, HAST = Hawaiian stilt, HAWD = Hawaiian duck, HAGO = Hawaiian goose, RAIL = either coots or moorhens

Table 6. Mean (standard error) rate of occurrence (number $12h^{-1}$ $100m^{-1}$ of fence) of various interactions between Hawaiian moorhens (HAMO), Hawaiian coots (HACO), Hawaiian stilts (HAST), Hawaiian ducks (HAWD) and Hawaiian geese (HAGO0 and fences placed around taro lo‘i at Hanalei National Wildlife Refuge, Kaua‘i, March – May 2013. Data summarized from *n* = 127 hour-long observation periods conducted during daylight hours, which totaled 457,200 individual camera images.

	Species				
Behavior	HAMO	HACO	HAST	HAWD	HAGO
Probe fence	39.6 ± 5.0	5.3 ± 1.9	0.4 ± 0.2	3.6 ± 1.6	1.0 ± 0.7
Climb over fence	17.9 ± 3.1	3.0 ± 1.6	0	0	0
Crawl under fence	1.0 ± 0.8	0	0	0	0
Run into fence	1.8 ± 0.9	0.3 ± 0.3	0	0	0
Fly into the fence	0.7 ± 0.4	0.4 ± 0.3	0	0	0.2 ± 0.2

2. Does fencing reduce the use of taro lo'i by waterbirds?

<u>Objective 2a: Compare abundance of waterbirds in paired fenced and unfenced lo'i during the day.</u>

We conducted waterbird counts during a 12-week period between 11 March and 29 May 2013. Both members of a replicate had to be surveyed during a specific time period within a week to be included in the analysis. Because of differences in timing of fence installation and removal and allocation of field effort during each week, sampling effort varied by replicate; H6/H9 were surveyed 34 times, K38/K41 were surveyed 28 times, and H3/H45 were surveyed 18 times. Not all species occurred frequently enough to permit analysis. For example, nēnē were only observed once in a lo'i during diurnal surveys. During one behavioral observation session we recorded a nēnē trying to climb a fence at night, but it failed to gain access to the lo'i. The only brood of any species recorded during surveys was a koloa female with a brood of Class 1a ducklings counted in H3 during weeks 8 and 9. Consequently, data summaries and statistical analyses focus on adult coots, moorhens, stilts, and koloa.

Coots occurred less frequently than expected in fenced lo'i than unfenced lo'i for all time periods (P's < 0.001; Table 7), which corresponded to lower mean abundance in fenced vs. unfenced lo'i ($F_{1,30}$ = 7.72; P = 0.009; Table 8). In contrast, the frequency of occurrence and mean abundance were similar between fenced and unfenced lo'i for all time periods for stilts (*P's* > 0.18) and koloa (*P's* > 0.60; Table 9). The mean abundance for moorhen was similar between fenced and unfenced lo'i for all time periods (P = 0.72), and frequency of occurrence was similar for midday and late day time periods (*P's* > 0.47). However, moorhens occurred more often than expected in fenced (60%) than unfenced (29.6%) lo'i during the early morning time period.

Differences among species in how fences influenced abundance and occurrence may reflect differences in how individuals of each species move among lo'i on the Refuge. For example, we observed very few stilts and koloa interacting with fences and we found their occurrence and abundance was similar between fenced and unfenced lo'i, which supports observations that individuals of both species frequently fly into and out of lo'i; thus, fences may be less of a barrier to adults during the day. In contrast, moorhens and coots most commonly walked between lo'i, which is consistent with results for objective 1 showing considerable interactions with fences. However, an increased ability or willingness by moorhens to climb reduced the effectiveness of fences in excluding this species.

The adult koloa with young ducklings in H3 indicates that Class 1a ducklings can move across a fence comprised of 1-inch mesh. Class 1a ducklings are young (1 week old) and their small size suggests they either moved through the fence mesh or crawled under the fence. Climbing is not documented in ducklings of Hawaiian duck or closely related mallard-type ducks. Either way, as the ducklings grow they will reach a size where moving through or under the fence is not possible, creating a situation where they are either prevented from entering or exiting the lo‘i. We only observed nēnē near fences on three occasions, and while they probed the fence on several occasions, we never saw a bird cross the fence boundary.

Objective 2b: Compare abundance of waterbirds in paired fenced and unfenced lo‘i at night.

We conducted eight nocturnal surveys of fenced lo‘i and six nocturnal surveys of unfenced lo‘i. Mean abundance did not differ for any species between fenced and unfenced lo‘i (*Ps* > 0.31; Table 10). The relatively higher mean value in fenced lo‘i for stilts resulted from one survey of a fenced lo‘i with 65 stilts.

Table 7. Frequency of occurrence (% of surveys when birds were recorded in a lo‘i) for Hawaiian moorhens and Hawaiian coots in fenced (*n* = 3) and unfenced (*n* = 3) taro lo‘i during three daytime periods over 12 weeks, March – May 2013, at Hanalei National Wildlife Refuge, Kaua‘i.

		Frequency of Occurrence			
Species	**Time period**[a]	**Fenced**	**Unfenced**	**χ^2–value**	***P*-value**
Hawaiian coot					
	early	12.0%	51.6%	9.37	<0.01
	middle	8.7%	48.0%	9.74	<0.01
	late	17.2%	51.2%	8.10	<0.01
Hawaiian moorhen					
	early	60.0%	40.0%	3.95	0.05
	middle	58.3%	51.8%	0.21	0.64
	late	54.5%	45.7%	0.53	0.47

[a] early = 0600-1000, middle = 1001-1400, and late = 1401-1800

Table 8. Mean daytime abundance [mean ± SE, (range)] of waterbirds in fenced (*n* = 3) and unfenced (*n* = 3) taro lo‘i at Hanalei National Wildlife Refuge, Kaua‘i, March – May 2013.

	Lo‘i status			
Species	**Fenced**	**Unfenced**	***F*-value**	***P*-value**
Hawaiian coot	0.15 ± 0.05 (0 – 3)	1.68 ± 0.25 (0 – 10)	8.26	0.007
Hawaiian moorhen	1.55 ± 0.23 (0 – 9)	1.20 ± 0.26 (0 – 19)	0.63	0.43
Hawaiian stilt	0.94 ± 0.14 (0 – 6)	0.82 ± 0.12 (0 – 5)	0.03	0.86
Hawaiian duck	0.25 ± 0.07 (0 – 2)	0.21 ± 0.07 (0 – 3)	0.12	0.74

* *n* = surveys conducted

Table 9. Frequency of occurrence (% of surveys recorded) for waterbirds in fenced (*n* = 3) and unfenced (*n* = 3) taro lo‘i during 29 surveys conducted during three daily time periods over a 12-week period between March – May 2013 at Hanalei National Wildlife Refuge, Kaua‘i.[a]

	Lo‘i status			
Species	**Fenced**	**Unfenced**	**χ^2–value**	***P*-value**
Hawaiian stilt	55.8%	48.2%	0.94	0.33
Hawaiian duck	14.3%	12.1%	0.18	0.68

[a] Data for time periods were combined as period-specific analyses found no differences.

Table 10. Mean nocturnal abundance [mean ± SE, (range)] of waterbirds in fenced and unfenced taro lo‘i at Hanalei National Wildlife Refuge, Kaua‘i, March – May 2013.

	Lo‘i status			
Species	**Fenced** *n* = 8	**Unfenced** *n* = 6	***F*-value**	***P*-value**
Hawaiian coot	0.25 ± 0.25 (0 – 2)	1.83 ± 1.83 (0 – 11)	0.16	0.70
Hawaiian moorhen	0.63 ± 0.63 (0 – 5)	0.33 ± 0.33 (0 – 2)	0.01	0.93
Hawaiian stilt	9.25 ± 8.02 (0 – 65)	0.17 ± 0.17 (0 – 1)	1.13	0.31
Hawaiian duck	1.25 ± 1.00 (0 – 8)	1.67 ± 0.65 (0 – 4)	0.64	0.44
Coot or moorhen	7.75 ± 4.12 (0 – 34)	3.50 ± 2.78 (0 – 17)		

* *n* = surveys conducted

3. How do waterbirds use young taro lo‘i and does their behavior differ between fenced and unfenced lo‘i?

Objective 3: Characterize and quantify waterbird behavior in young taro lo‘i and compare behavior of waterbirds in fenced and unfenced lo‘i.

The proportion of time spent in different behaviors during the day was similar between fenced and unfenced lo‘i for coots ($F_{6,30}$ = 0.93; P = 0.49), moorhens ($F_{6,41}$ = 0.78; P = 0.59), and stilts ($F_{6,22}$ = 1.32; P = 0.29; Table 11), which indicated we could not detect a general effect of fencing on behavior. There was no significant difference in time spent foraging between birds in fenced and unfenced lo‘i for coots (P = 0.23), moorhens (P = 0.17), or stilts (P = 0.45); although, there was a tendency for birds to spend less time foraging in fenced than unfenced lo‘i.

Because we could not detect differences in behavior between birds in fenced and unfenced lo‘i, we combined all time activity budget sessions (fenced, unfenced, and other) and tested for a more general difference in behavior among species. We found diurnal behaviors differed among species ($F_{12,354}$ = 5.12; P < 0.001; Table 12). Overall, feeding was the most frequently observed behavior for all species followed by locomotion and maintenance. Coots spent less time foraging than moorhens (P = 0.008) but they were similar to stilts (P = 0.21). Coots spent more time in movement behaviors (locomotion) than moorhens (P = 0.04), which moved more than stilts (P = 0.001). Also, both coots (H_1 = 10.25, P = 0.001) and moorhens (H_1 = 7.84, P = 0.005) allocated less time to alert behavior than stilts.

Objective 4: Characterize the ways that waterbirds interacted with taro plants and their relative frequency of occurrence.

Although both moorhens and coots spent considerable time feeding when in young taro lo‘i, they spent little time feeding on or generally interacting with taro plants. During the day, the mean percent time spent interacting with taro plants (all behaviors combined) was 3.6 ± 0.9% (range 0 – 57.7%, n = 80) for coots and 4.5 ± 1.1% (range 0 – 66.9%, n = 73) for moorhens, which for a 12-hour day that projects to 32.4 min for moorhens and 25.9 min for coots.

Time spent interacting with taro plants was similar between moorhens and coots ($F_{1,79}$ = 0.05, P = 0.81). Only two coots and one moorhen spent more than 25% of their time interacting with taro plants and in those three cases the birds were roosting on a plant. When a bird was observed interacting with a taro plant (*n* = 60 for coots and *n* = 55 for moorhens), the most frequently observed behavior was for birds to have their head under water near the base of a plant (Table 13). The next two most common behaviors were pecking at the leaf and stem. Foraging on newly emerging leaves was observed for both species (e.g., Appendix G), but it comprised < 9% of all taro interactions.

No individual behaviors related to the use of taro plants as structure (for roosting, walking or conducting maintenance activities) differed between coots and moorhens. That said, in aggregate, moorhens spent more time using taro plants as structure (11.3 ± 3.0%) than coots (5.0 ± 2.2%). Moorhens are more arboreal (Bannor and Kiviat 2002) than coots and smaller in size, which is consistent with their ability to use young taro plants as roosting structure.

Nocturnal behavior data were difficult to collect but limited observations suggested that moorhens were largely inactive at night while in loʻi (Table 14). Although coots were more active than moorhens at night, the most common behavior was resting (53%) followed by maintenance (20%); they only spent about 12% of their time feeding. Images from cameras documented several interactions with taro at night including showing a moorhen using a taro stem for roosting (Appendix H), a taro plant being knocked over by nēnē (Appendix I), and one image of a rat feeding on a taro plant (Appendix J) .

Considering the results from objectives 3 and 4 together, the results confirm that taro loʻi provide useful habitat for Hawaiian waterbirds. For example, all birds spent considerable time foraging in loʻi. However, high foraging effort (i.e., large percentage of time spent foraging) could reflect low food abundance (i.e., low food abundance) that require birds to forage for long periods to meet their daily energetic needs. There are no published studies that quantify moorhen foraging behavior that could serve as a comparison against results from this study. Moorhens and coots will feed on both plants and invertebrates (Bannor and Kiviat 2002). While we could not see birds feeding on invertebrates some of their behaviors (pecking at stem) are consistent with consuming invertebrates. There was very little native wetland forage plants available in loʻi during our study, suggesting that birds needing vegetation in their diet would have to forage on taro or forage on surrounding dikes or ditches (the latter being quite common). Diversifying the plant composition within loʻi would likely improve the habitat conditions for both moorhens and coots. Given that birds spent considerable time foraging in loʻi but little time foraging on the dominant plant resource in loʻi (taro), a closer look at the diet for moorhens and coots would help determine the resources specifically sought by these species when feeding in lo‘i.

While moorhens and coots did interact with taro plants, taro was not the primary focus of feeding moorhens and coots in taro lo‘i. When they interacted with taro plants, the most common behavior was a bird with its head under water oriented towards the base of the taro plant. We categorized that behavior as “interacting with taro” because of the bird proximity to the plant, but in the absence of more complete information, we cannot conclude that moorhens and coots were foraging on taro plants when their head was under water. After HEAD UNDER WATER, the most common behaviors were various levels of disturbing leafs and stems ranging from the lowest level (pecking) to higher levels (tugging and eating).

Farmers have indicated that moorhens and coots damage taro plants by foraging on newly emerging leaves. The total time possibly attributable to this behavior during day time was 0.4% for coots and 0.6% for moorhens (multiply the proportion of time spent interacting with taro by the proportion of time spent feeding on taro stems and leaves), which projects to 2.9 minutes per 12 hours of daylight for coots and 4.3 minutes for moorhens. However, it is not clear how much time is required to significantly damage a plant and the impact to any particular lo‘i will depend on the population size of birds using the lo‘i. If HEAD UNDER WATER does represent foraging on taro the total time spent feeding on taro was 12.4 min for coots and 12.8 min for moorhens.

Table 11. Allocation of time (%) among behaviors by Hawaiian coots (HACO), Hawaiian moorhens (HAMO), and Hawaiian stilts (HAST) in fenced and unfenced taro lo‘i during the day at Hanalei National Wildlife Refuge, Kaua‘i, March-May, 2013.

	HACO		**HAMO**		**HAST**	
	Fenced	**Unfenced**	**Fenced**	**Unfenced**	**Fenced**	**Unfenced**
Behavior	*n* = 18[a]	*n* = 19	*n* = 25	*n* = 23	*n* = 20	*n* = 9
Foraging	44.8 ± 4.6	54.5 ± 5.0	57.3 ± 5.0	64.5 ± 4.8	59.0 ± 8.2	72.2 ± 5.4
Maintenance	8.5 ± 2.9	15.6 ± 4.1	13.8 ± 3.1	12.8 ± 3.9	9.3 ± 2.7	4.8 ± 3.7
Rest	5.3 ± 3.4	1.0 ± 0.7	1.1 ± 0.7	0.7 ± 0.5	8.9 ± 4.0	0.8 ± 0.8
Locomotion	36.8 ± 5.1	24.5 ± 3.4	18.7 ± 4.0	17.9 ± 3.6	12.1 ± 4.3	7.5 ± 2.6
Alert	3.7 ± 0.9	2.6 ± 0.9	5.5 ± 1.3	2.5 ± 0.6	8.6 ± 3.5	10.2 ± 2.1
Social	0.9 ± 0.4	1.6 ± 0.7	3.6 ± 1.4	1.5 ± 0.4	2.2 ± 0.8	4.5 ± 1.2

[a] *n* indicates the number of observation sessions that contributed data for each column.

Table 12. Allocation of time (%) among behaviors by Hawaiian coots (HACO), Hawaiian moorhens (HAMO), and Hawaiian stilts (HAST) in taro lo‘i during the day at Hanalei National Wildlife Refuge, Kaua‘i, March-May, 2013.

	Species		
Behavior	**HACO** *n* = 74[a]	**HAMO** *n* = 78	**HAST** *n* = 33
Foraging	49.2 ± 2.6	62.8 ± 2.6	60.2 ± 5.6
Maintenance	17.7 ± 2.3	12.8 ± 1.8	10.3 ± 2.8
Rest	4.0 ± 1.6	1.0 ± 0.4	5.7 ± 2.5
Locomotion	24.8 ± 2.0	18.0 ± 1.8	11.9 ± 3.0
Alert	3.0 ±0.5	3.5 ± 0.6	9.2 ± 2.3
Social	1.3 ± 0.3	1.8 ± 0.5	2.7 ± 0.6

[a] *n* indicates the number of observation sessions that contributed data for each column.

Table 13. How Hawaiian coots (HACO) and Hawaiian moorhens (HAMO) allocated their time (percent ± SE with range in parentheses) among behaviors during the percent of the day they interacted with taro plants at Hanalei National Wildlife Refuge, Kauaʻi, March-May, 2013.

	Species	
Behavior	**HACO** (*n* = 60 [a])	**HAMO** (*n* = 55)
Head under water at the base of a plant	36.1 ± 5.2 (0 – 100)	25.1 ± 4.9 (0 – 100)
Peck at leaf	17.6 ± 3.5 (0 – 100)	22.0 ± 3.6 (0 – 100)
Peck at stem	26.1 ± 4.3 (0 – 100)	18.3 ± 3.2 (0 – 100)
Peck at base of plant	0.4 ± 0.4 (0 – 23.0)	1.3 ± 1.1 (0 – 60.1)
Eat leaf	8.0 ± 2.4 (0 – 100)	8.9 ± 2.0 (0 – 54.5)
Eat stem	3.8 ± 1.2 (0 – 48.5)	5.4 ± 1.2 (0 – 34.9)
Up root or knock plant over	0.0	0.0
Tug leaf	0.5 ± 0.3 (0 – 9.8)	0.4 ± 0.2 (0 – 9.5)
Tug stem	0.7 ± 0.4 (0 – 25.0)	3.4 ± 1.3 (0 – 49.2)
Perch on a plant while loafing	0.5 ± 0.5 (0 – 30)	1.4 ± 1.4 (0 – 77.2)
Stand on plant	0.1 ± 0.1 (0 – 1.0)	1.6 ± 1.2 (0 – 64.6)
Stand on plant while performing maintenance activities	3.2 ± 2.2 (0 – 96.3)	2.3 ± 1.9 (0 – 100)
Walk on or swim over a plant	3.0 ± 1.8 (0 – 100)	9.7 ± 2.8 (0 – 100)

[a] *n* indicates the number of observation sessions that contributed data for each column.

Table 14. Nocturnal behaviors of Hawaiian coots (HACO) and Hawaiian moorhens (HAMO) in young taro lo‘i (<100 days old) at Hanalei National Wildlife Refuge, Kaua‘i, March – May 2013.

	Species	
Behavior	**HACO** *n* = 16	**HAMO** *n* = 6
Resting	53.7 ± 11.1 [a]	91.5 ± 6.3
Feeding [b]	12.6 ± 6.4	3.5 ± 3.5
Locomotion	9.8 ± 3.6	2.6 ± 2.1
Maintenance	19.7 ± 7.9	1.9 ± 0.6
Social	2.2 ± 1.1	0
Alert	1.3 ± 0.09	0.6 ± 0.6

[a] Data reported as mean percent time (± SE); *n* indicates the number of observation sessions that contributed data for each column.

[b] general foraging behavior; we could not determine what was being foraged upon.

4. Do fences improve the survival and health of young taro plants?

<u>Objective 5: Measure and compare plant survival and indices of plant health between fenced and unfenced lo‘i.</u>

Plant survival in a lo‘i ranged from 56.0 to 93.6% and was higher in fenced than unfenced lo‘i (t = 3.03, P = 0.04). The difference in plant survival between fenced and unfenced lo‘i in each replicate ranged from 12.6% to 30.3% (Fig. 2). The fence impact on plant survival may have been biased low as the fence around H3 was removed early and we were prevented from measuring plants until several weeks after the fence was removed because of use of H3 by a Hawaiian duck brood. Mean corm basal area (t = 0.69, P = 0.53), mean number of intact leaves per plant, (t = 0.21, P = 0.84), and mean total leaf area per plant (t = 0.92, P = 0.41) was similar between fenced and unfenced lo‘i (Table 15). Overall, the mean corm area was 19.43 ± 0.56 cm^2, mean number of leaves was 2.18 ± 0.06, and mean leaf area was 979 ± 29 cm^2 (Table 16).

It is not clear how plant performance metrics collected when taro plants are three months old correlates to taro yield when the plants are harvested. More sampling to include the period of taro harvest is needed to make strong conclusions, but fences did increase plant survival during the fence period.

Table 15. Comparison of mean basal plant area (cm^2), number of intact leaves per plant, and total leaf area per plant (cm^2) between fenced (n = 3) and unfenced (n = 3) lo‘i at Hanalei National Wildlife Refuge, Kaua‘i, HI, March-May 2013.

	Fenced			**Unfenced**		
Metric	**LCL[a]**	**Mean ± SE**	**UCL**	**LCL**	**Mean ± SE**	**UCL**
Basal Area	8.3	20.3 ± 1.5	32.4	11.9	18.2 ± 1.5	24.5
Leaves	0.7	2.2 ± 0.6	3.7	1.0	2.1 ± 0.3	3.2
Leaf Area	337	1058 ± 290	1779	468	881 ± 96	1295

[a]LCL = lower 95% confidence limit for the mean; UCL = upper limit.

Table 16. Mean basal plant area at base of stem (cm^2), number of intact leaves per plant, and total leaf area per plant (cm^2) for fenced and unfenced lo‘i at Hanalei National Wildlife Refuge, Kaua‘i.

Lo‘i	**Status**	**Basal Area**	**Leaves**	**Leaf Area**
K9	Fenced	24.08 ± 1.47 [a]	2.48 ± 0.13	1267.3 ± 68.9
n = 48		(21.11 – 27.04)	(2.21 – 2.75)	(1128.6 – 1406.0)
K6	Unfenced	18.59 ± 0.90	2.33 ± 0.09	760.2 ± 45.7
n = 42		(16.76 – 20.41)	(2.14 - 2.52)	(667.9 - 852.5)
K38	Fenced	14.89 ± 0.98	1.52 ± 0.11	726.8 ± 56.7
n = 42		(12.91 – 16.88)	(1.30 – 1.74)	(612.2 - 841.4)
K41	Unfenced	15.52 ± 1.10	1.63 ± 0.10	811.6 ± 59.5
n = 40		(13.28 – 17.75)	(1.42 – 1.83)	(691.3 – 931.8)
H3	Fenced	22.14 ± 1.24	2.65 ± 0.13	1181.0 ± 61.1
n = 43		(19.64 – 24.63)	(2.38 – 2.91)	(1057.8 - 1304.2)
H45	Unfenced	20.51 ± 1.72	2.42 ± 0.15	1071.2 ± 83.2
n = 40		(17.02 – 24.00)	(2.12 - 2.73)	(902.9 - 1239.6)
Combined [b]		**19.43 ± 0.56**	**2.18 ± 0.06**	**979 ± 29**
n = 255		**(18.33 – 20.53)**	**(2.07 - 2.30)**	**(921 – 1036)**

[a] *n* = total number of plants measured in the lo‘i.
[b] Because means were similar between fenced and unfenced lo ‘i, we generated a combined mean for all plants.

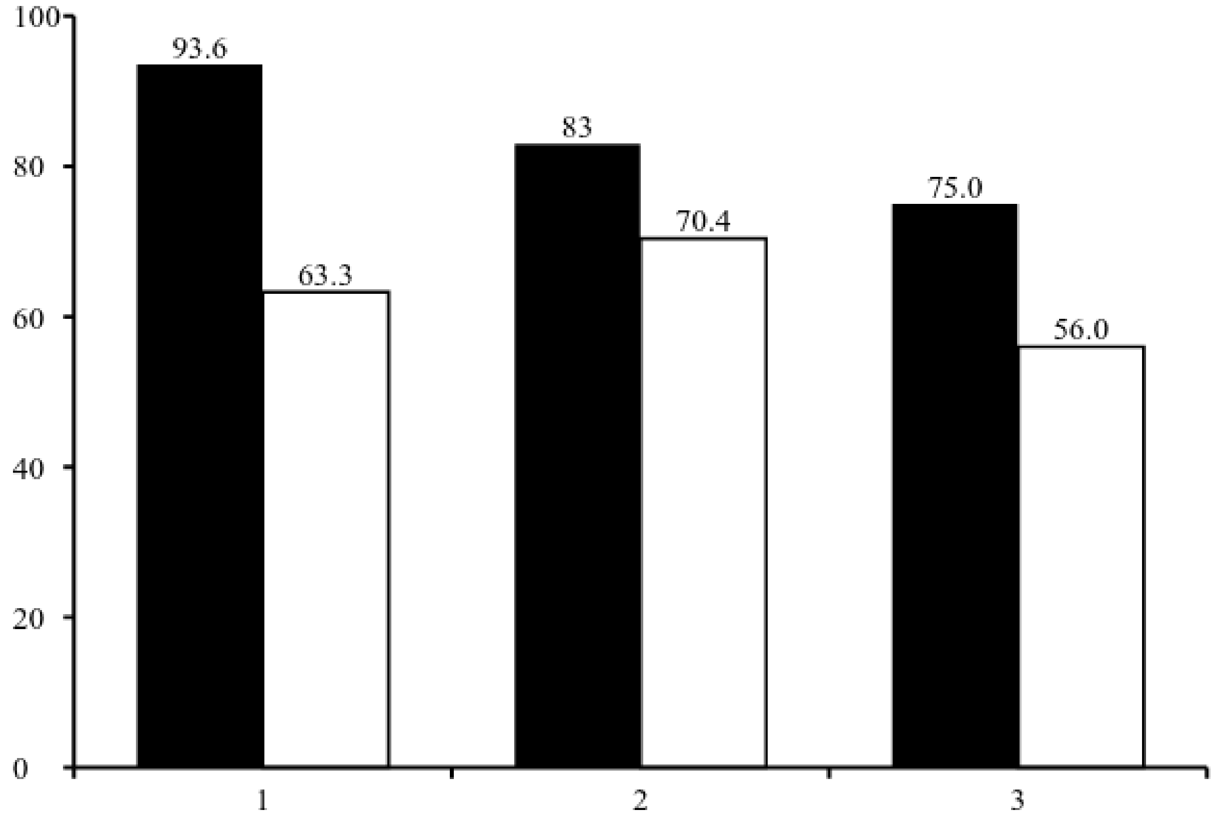


Figure 2. Survival (%) of taro plants in paired fenced and unfenced lo‘i (n=3) at Hanalei National Wildlife Refuge, Kaua‘i, HI. Although lo‘i ranged in age from 70-104 days, the age of fenced and unfenced lo’i in pairs was similar.

CONCLUSIONS

Our study included only three replicate pairs of fenced and unfenced lo‘i, which is a small sample size. Consequently, we caution against trying to draw definitive conclusions from these results. That said, some patterns did emerge from the data that are worth considering and might serve to target additional work if such was deemed desirable. Fundamentally, results do provide insight into how Hawaiian waterbirds use young taro lo‘i, which could help in future conversations about taro farming at the Refuge. The following patterns observed in the data relate to concerns about the impact of fences on waterbirds as outlined in the BO:

1. Fences created obstacles that resulted in collisions for waterbirds; the frequency of high impact collisions were highest for moorhens. However, we could not quantify the effect of these interactions on individual birds or waterbird vital rates, so it is unknown what effect these interactions would have on the population dynamics of any species.
2. Fences were most effective at excluding coots from lo‘i, which indicated that fenced reduced habitat availability for coots. There was little data on nēnē for comparison with this species.
3. The abundance of stilts, moorhens, and koloa did not differ between fenced and unfenced lo‘i. Moorhens were commonly seen climbing fences into and out of lo‘i.
4. Waterbird behaviors did not differ between fenced and unfenced lo‘i.

Coots and moorhens commonly fed in lo‘i but very little of that time was spent feeding on taro plants. More work on the diet of these species and nēnē would be helpful for understanding the foods consumed in lo‘i. Taro plants in fenced lo‘i experienced higher survival, but measurements of plant growth for surviving plants were similar between plants in fenced and unfenced lo‘i. Because the coot was the only species that was measurably excluded by the fence, coots may have a greater impact on taro plants than moorhens, stilts, or koloa. Nēnē were active at night grazing on lo‘i dikes and we did observe nēnē in lo‘i at night, but the frequency of lo‘i use at night is unknown and we were unable to characterize their behavior in lo‘i because the taro plants obstructed our view. Finally, given our low nocturnal sampling effort and the random placement of the camera relative to any known distribution patterns by rats, the fact that we captured a rat on camera is noteworthy and might imply rats are common in lo‘i at night and, therefore, a factor to be considered in future discussions about crop depredation.

ACKNOWLEDGMENTS

We thank the staff at Hanalei National Wildlife Refuge, particularly Kim Uyehara, Mike Mitchell, and Shannon Smith. We also thank refuge taro farmers Rodney and Karol Haraguchi, Mark Koga, and Alex Diego for accommodating our data collection activities in lo‘i they farm; and we generally thank all the taro farmers for responding to requests for information and sharing their knowledge of taro culture and their observations of how waterbirds use taro lo‘i. Individuals who participated in discussions to help shape the monitoring objectives or provided comments on the methodology associated with the monitoring include: K. Uyehara, M. Mitchell, S. Smith, K. Kilbride, B. Flanders-Wanner, J. Kenyon, C. Ogura, J. Underwood, R. Yamakawa. Thanks to C. Smith, M. Kappes, M. Bogardus, J. Macaulay, K. Dickson, M. McKenzie, and D. Spresser, who volunteered time during study preparation or helped collect data. Funding for this project was provided by the U. S. Fish and Wildlife Service.

LITERATURE CITED

Altmann, J. 1974. Observational study of behavior: sampling methods. Behaviour 49:227-267.

Baldassarre, G. A, S. L. Paulus, A. Tamisier, and R. D. Titman. 1988. Workshop summary: techniques for timing activity of wintering waterfowl. Pages 181–190 *in* M.W. Weller, editor. Waterfowl in winter. University of Minnesota Press, Minneapolis, Minnesota, USA.

Bannor, B. K. and Erik Kiviat. 2002. Common Gallinule (*Gallinula galeata*), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/685doi:10.2173/bna.685

Brisbin, Jr., I. Lehr and T. B. Mowbray. 2002. American Coot (*Fulica americana*), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/697adoi:10.2173/bna.697a

Chan, L.-F., H.-Y. Lu, C.-T. Lu, and C.-H. Lai. 1995. Relationship between leaf area and dry biomass production in wetland taro [*Colocasiaesculenta* (L.) Schott]. Journal of Agricultural Research of China 44:59-71.

Crook, S. L., W. C. Conway, C. D. Mason, and K. J. Kraai. 2009. Winter time-activity budgets of diving ducks on eastern Texas reservoirs. Waterbirds 32:548-558.

Dugger, B. D. and M. J. Petrie. 2000. Geographic variation in foraging patterns of pre-incubating female Mallards. Canadian Journal of Zoology 78:2240-2243.

Jacobs, B. C. and V. Chand. 1992. Large headsets and improved cultivar enhance growth and development of taro (*Colocasia esculents* [L.] Schott) during establishment. Journal of Agronomy and Crop Science 168:119-127.

Lu, H.-Y., C.-T. Lu, M.-L. Wei, and L.-F. Chan. 2004.Comparison of different models for nondestructive leaf area estimation in taro. Agronomy Journal 96:448-453.

Martin, P., and P. Bateson. 2007. Measuring behavior: an introductory guide, 3rd edition. Cambridge University Press, Cambridge, UK. 176pp.

Paulus, S. L. 1988. Time-activity budgets of mottled ducks in Louisiana in winter. The Journal of Wildlife Management 52:711-718.

Pratt, H. D. and I. L. Brisbin Jr. 2002. Hawaiian Coot (*Fulica alai*), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America online: http://bna.birds.cornell.edu/bna/species/697bdoi:10.2173/bna.697b

Ramsey, F. L., and D. W. Schafer. 2002. The Statistical Sleuth, A Course in Methods of Data Analysis, 2ndedtion. Duxbury Press, Pacific Grove, California, USA.

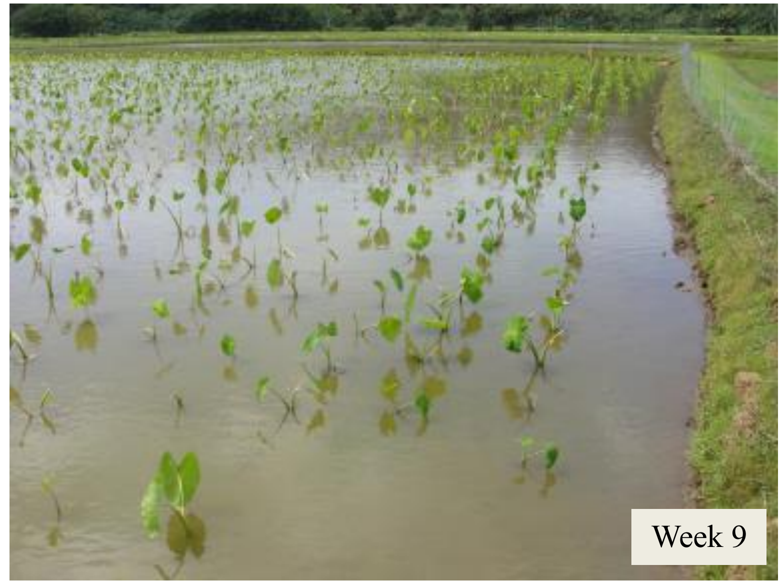
Schaffer, B. and S. O'Hair. 1987. Net CO_2 assimilation of taro and cocoyam as affected by shading and leaf age. Photosynthesis Research 11:245-251.

U.S. Fish and Wildlife Service. 2011. Recovery Plan for Hawaiian Waterbirds, Second Revision. U.S. Fish and Wildlife Service, Portland, Oregon.233 pp.

U.S. Fish and Wildlife Service. 2012. Endangered Species Act Section 7 Consultation for Installation of Temporary Exclusionary Fencing on Hanalei National Wildlife Refuge. File number Rl-12S19-2012-N-OOI.

APPENDIX A. A series photos of fenced and unfenced lo‘i taken from the same location at Hanalei National Wildlife Refuge, March – May 2013. The age of each lo‘i, in weeks, was calculated from the last day that planting occurred in the lo‘i.

Appendix A: Lo‘i H3 (fenced)



Appendix A: Lo‘i H45 (unfenced)


Week 5


Week 7


Week 9


Week 13, May 29, 2013

Appendix A: Lo‘i K9 (fenced)

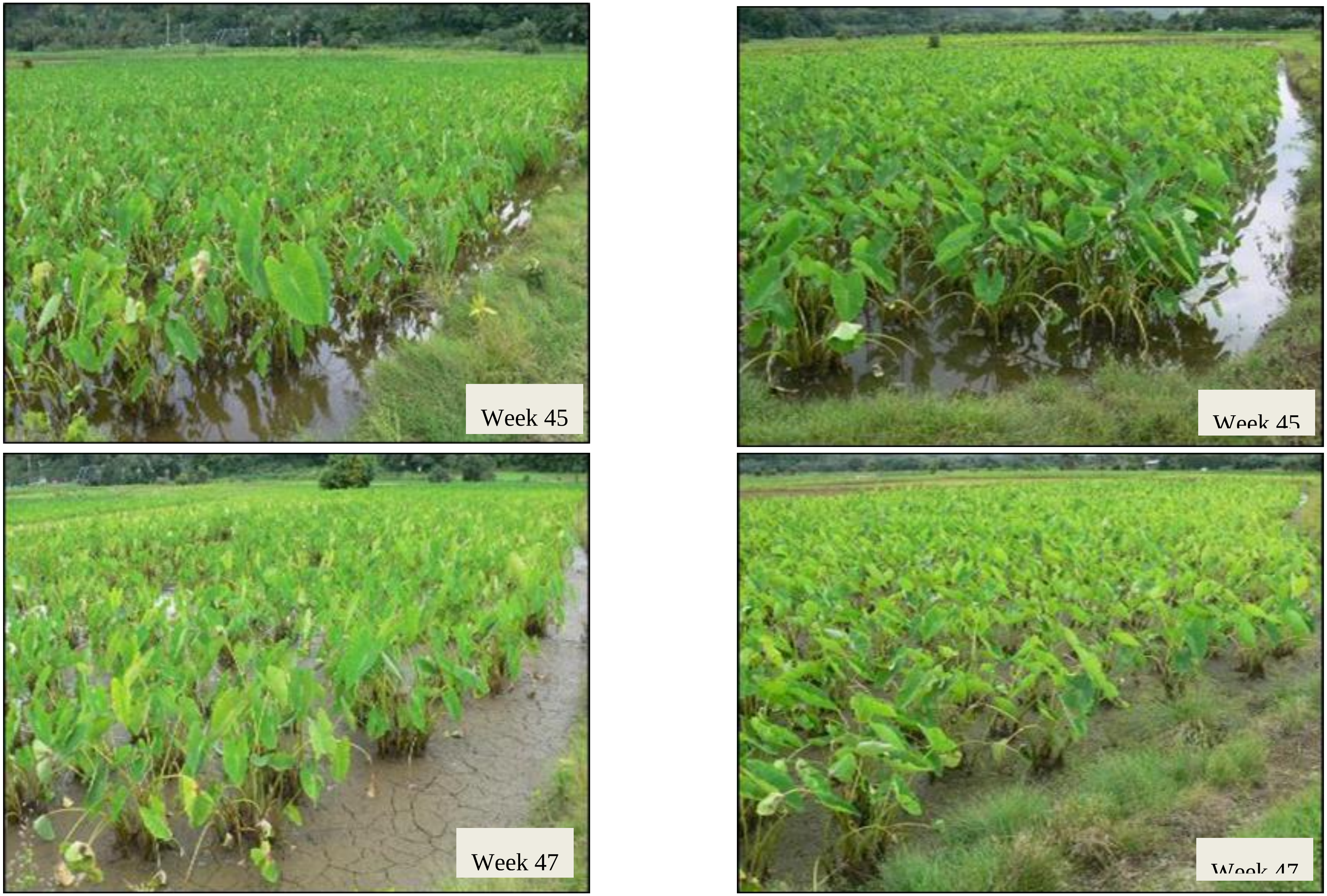
Appendix A: Lo‘i K6 (unfenced)

Appendix A: Lo‘i K38 (fenced)

Appendix A: Lo‘i K41 (unfenced)

APPENDIX B. Photos of fenced and unfenced lo‘i at Hanalei National Wildlife Refuge taken on 2 January 2014, approximately seven months after fences were removed. Photos on the left were taken from the same location as photos in Appendix A; photos on the right were taken from the opposite corner (diagonal) from the original location. Lo‘i age was calculated from the last day that huli were planted in the lo‘i.

Appendix B: fenced lo‘i K9 (top), unfenced lo‘i K6 (bottom)



Appendix B: fenced lo‘i K38 (top); unfenced lo‘i K41 (bottom).

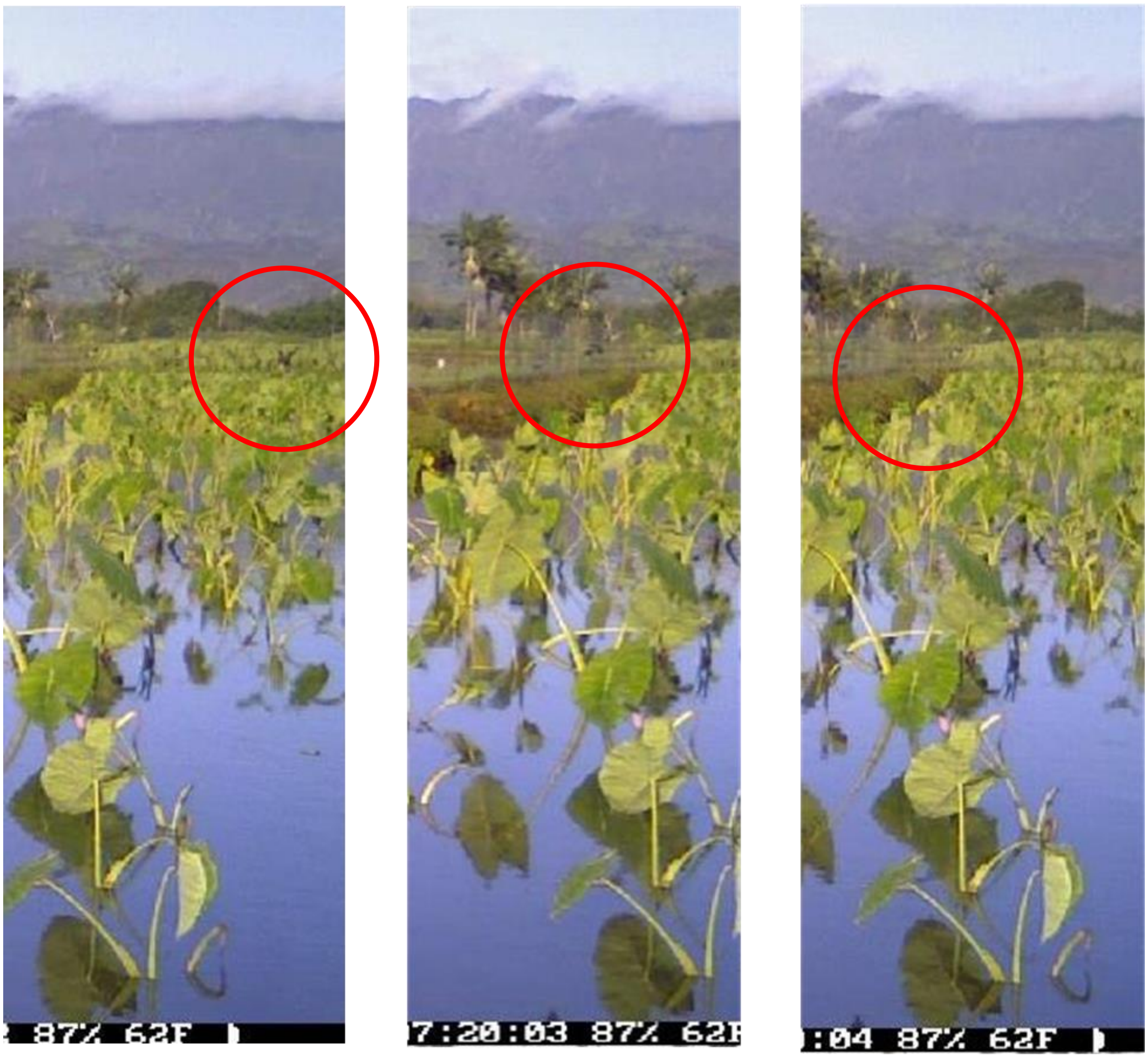
Appendix B: fenced lo‘i H3 (top); unfenced lo‘i H45 (bottom).

APPENDIX C. Hawaiian moorhen with frontal shield caught in mesh of fence at Hanalei National Wildlife Refuge, Kaua‘i, May 2013.

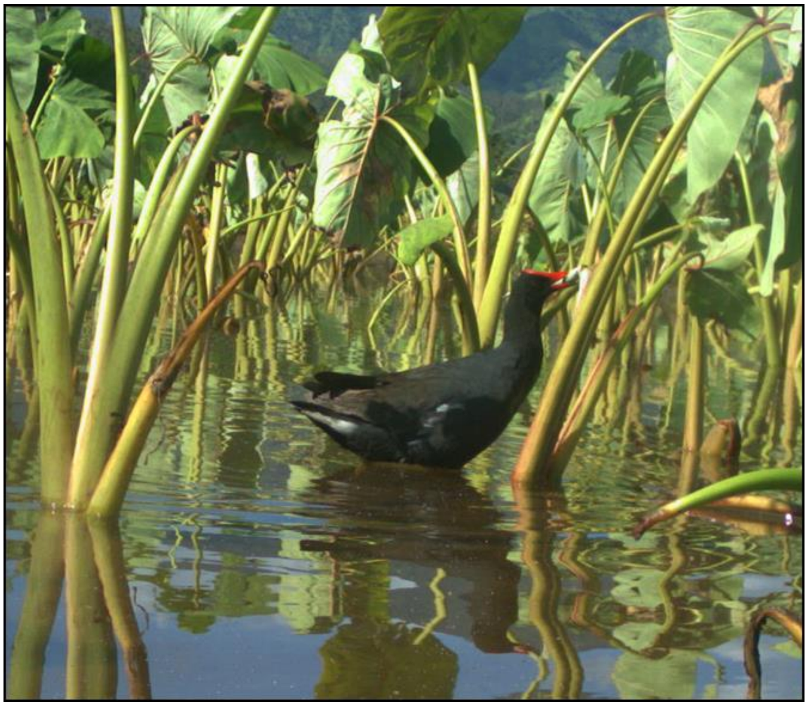
APPENDIX D: Hawaiian moorhen climbing a fence to leave a taro lo‘i (left to right, top to bottom) at Hanalei National Wildlife Refuge, 11 March 2013.

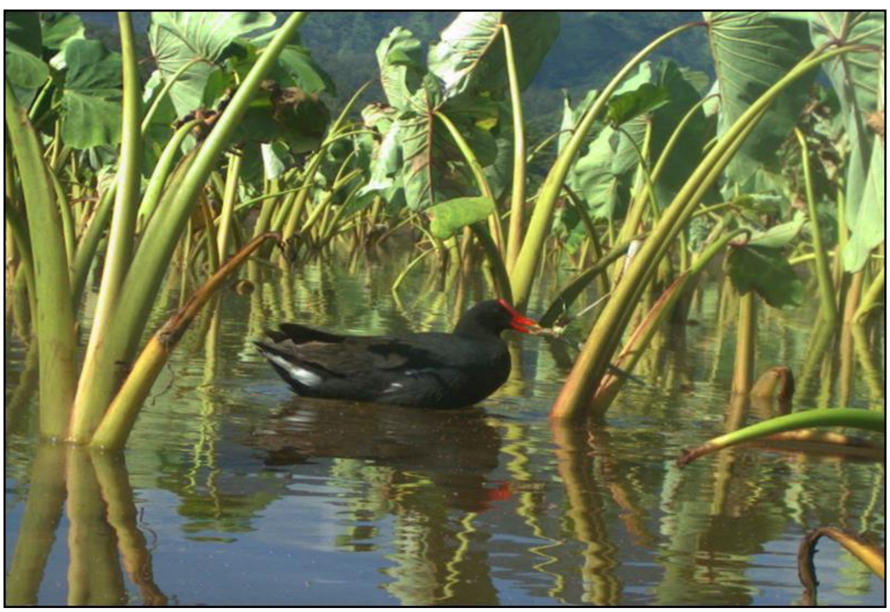
APPENDIX E: Hawaiian moorhen running and flying into the fence installed around lo'i H3 at Hanalei National Wildlife Refuge, 10 April 2013.

APPENDIX F: Hawaiian coot flying into fence installed around lo‘i H3 at Hanalei National Wildlife Refuge, 16 April 2013.

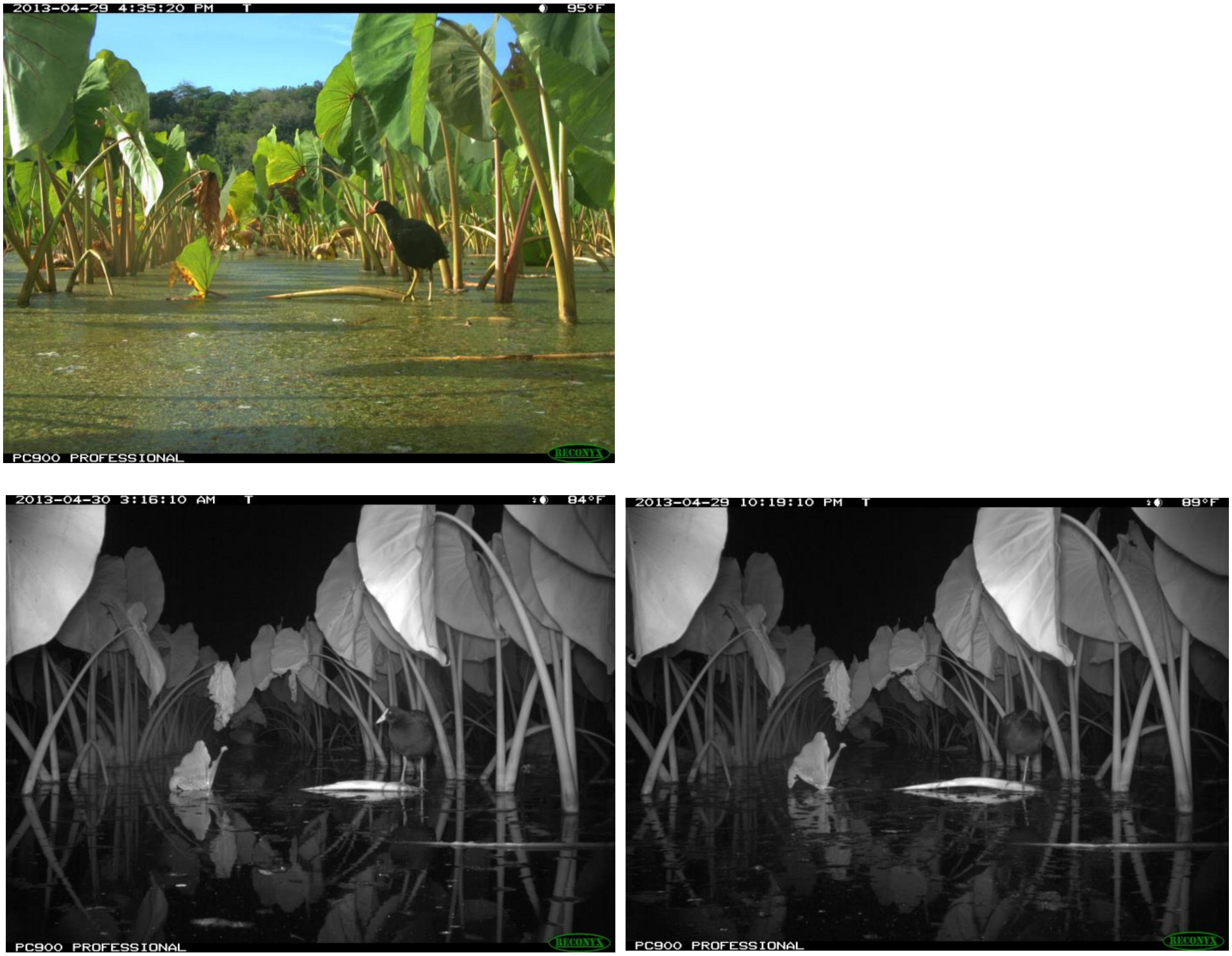


APPENDIX G. Top: Hawaiian Moorhen foraging on an emerging leaf of a young (<100 days) taro plant. Photos taken at Hanalei National Wildlife Refuge, Kaua'i, April 2013.

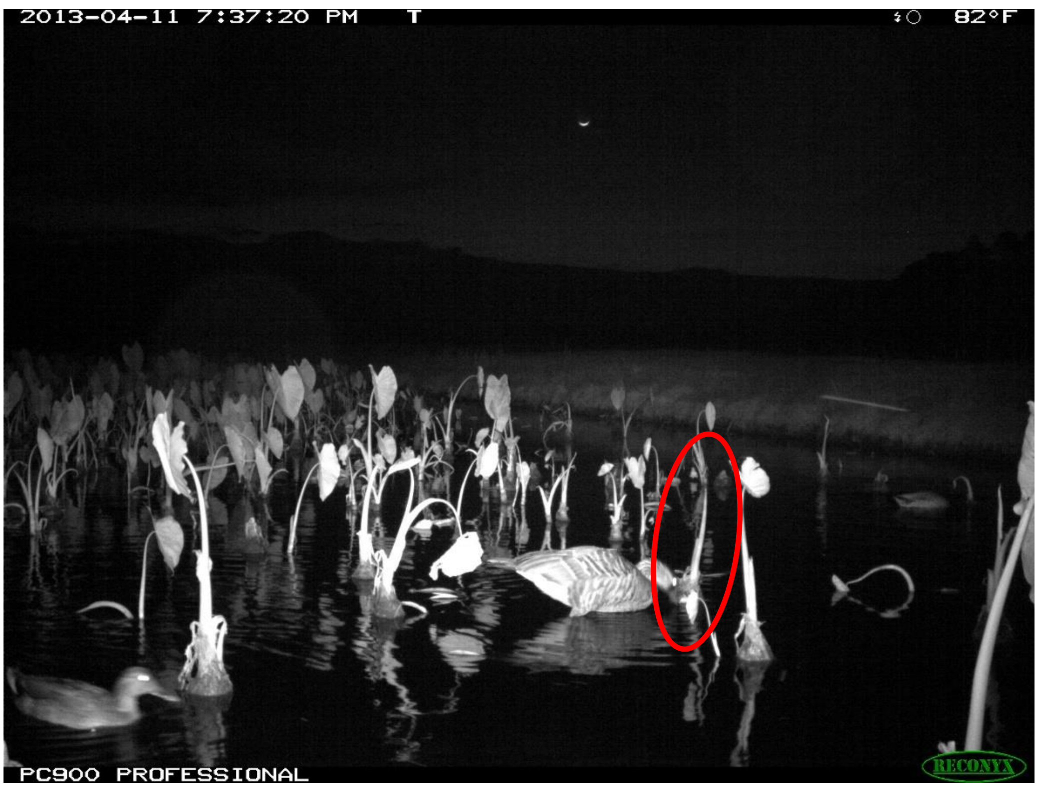




APPENDIX H. Hawaiian Moorhen roosting on young (<100 days) taro plant at Hanalei National Wildlife Refuge, Kaua‘i, April 2013.



APPENDIX I. Hawaiian geese knocking a taro plant over at Hanalei National Wildlife Refuge, Kauaʻi, April 2013.




2013-04-11 7:39:20 PM T
83°F
PC900 PROFESSIONAL
RECONYX


2013-04-11 7:42:05 PM T
83°F
PC900 PROFESSIONAL
RECONYX

APPENDIX J. Rat foraging on a mature taro plant at Hanalei National Wildlife Refuge, Kaua‘i, April 2013.