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Vertebrate Animal Behaviors and Abundances on Estuarine Shorelines Stabilized with Biodegradable Materials Utilizing Wildlife Cameras

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Cover Page Footnote

I would like to extend my sincerest gratitude to the University of Central Florida Coastal and Estuarine Ecology Laboratory for their assistance and guidance in data collection and analyses process, especially to P. Sacks, and to the Canaveral National Seashore for field access. I would also like to thank the University of Central Florida Office of Undergraduate Research for providing the 2021-2022 University of Central Florida Student Research Grant, Summer 2021 Summer Undergraduate Research Fellowship program offered by UCF's Office of Undergraduate Research, and the Disney Wildlife Conservation Fund (to L. Walters) for providing wildlife cameras critical to the study.

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Vertebrate Animal Behaviors and Abundances on Estuarine Shorelines Stabilized with Biodegradable Materials

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ABSTRACT: Living shoreline stabilization is a restoration technique that utilizes natural materials as breakwaters, plus vegetation landward of the breakwaters, to protect coastlines. This research does not provide information about how new, biodegradable restoration materials affect vertebrates that utilize these shorelines. For this project, I monitored 18 restoration sites along Canaveral National Seashore with wildlife trail cameras: 3 made with cement-infused jute breakwaters, 3 with metal gabion oyster shell breakwaters, and 4 with previously used breakwaters manufactured from plastic mesh oyster shell bags. This project used 4 sites as positive controls (intact vegetation) and 4 as negative controls (highly eroded, no vegetation). Wildlife cameras were used to continuously observe vertebrates for 1-month intervals, pre- and post-stabilization. I observed and recorded a total of 1,044 vertebrates (993 mammals, 51 birds), representing 15 species. The most abundant of these species was *Procyon lotor* (North American raccoon), and the least abundant was *Anas platyrhynchos* (mallard duck). The most common behavior among all recorded species was foraging and the least common was swimming. There were 3 observed vertebrate species utilizing restoration materials as a perch for stalking prey, suggesting that the presence of such material did not inhibit their behaviors. These vertebrates damaged neither the restoration materials nor plants deployed behind the breakwaters. Thus, there were no recorded observations of negative vertebrate interactions with these materials. However, all species had fewer post-restoration observations at all control sites.

KEYWORDS: Living shoreline, breakwaters, vertebrate behaviors, vertebrate abundances

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INTRODUCTION

Shorelines, especially those found to contain estuaries, are regions of high biodiversity considered vulnerable to various damaging natural and anthropogenic factors. Wind, waves, and severe weather events such as hurricanes erode and destroy coastal habitats critical to biodiversity (e.g., Ellison et al., 1991; Zhang et al., 2004; Overpeck & Weiss, 2009). Rising sea levels are largely responsible for an even greater rate of erosion than in past years (Leatherman et al., 2011), as increasing intense tropical storms and severe weather patterns pose another dire risk to shorelines (Scavia et al., 2002). Increasing urban development around these vulnerable estuaries has resulted in shoreline alterations for public and private properties. Additionally, mosquito control has reduced natural shoreline habitat acreage (Brockmeyer et al., 2021), and recreational activities such as boating have been seen to alter shorelines (McClenahan et al., 2020; Fillyaw et al., 2021; Walters et al., 2021).

Because shorelines are a crucial habitat for various wildlife, including a vast diversity of vertebrates, damage to shorelines imposes a substantial concern for the future of animal diversity and abundance among coastal populations. Seawalls and other protective measures are being deployed globally to reduce shoreline loss. Unfortunately, this type of hard armoring has displayed adverse effects by decreasing connectivity and causing the loss of shoreline habitats (McClenahan et al., 2020; Fillyaw et al., 2021). Although effective at reducing erosion rates in the short-term, hard-armored shorelines neither provide additional ecosystem services nor have the ability to adapt to future environmental changes, such as sea level rise. Other methods utilizing dunes, native vegetation, or ecosystem restoration for shoreline defense are growing in usage as an alternative to hard armoring (Spalding et al., 2014). One method, establishing a living shoreline, utilizes natural materials, including native plant species and oysters, to prevent erosion (Chaya et al., 2019). This living shoreline technique often uses oysters to provide ecosystem services like water filtration, sediment stabilization, and wave energy reduction (Currin et al., 2010; Morris et al., 2021). Likewise, living shoreline restoration methods frequently include mangroves and other native plants to provide abundant ecosystem services, like water filtration, nutrient cycling, and habitat, in addition to reducing overall shoreline erosion rates.

Understanding the abundance and behaviors of vertebrate animals using stabilized shorelines is of great ecological importance and a growing research focus. The goal of this research was to understand vertebrate use and behaviors at restored sites during both pre-restoration and post-restoration. Ecologists should know the behaviors of animals at restoration sites, as such information is critical for vertebrate species' well-being and the longevity and success of restoration materials. For example, *Procyon lotor* (North American Raccoon), one of the most abundant species on coastlines in the Southeast USA, has been known to destroy vegetation and sea turtle nesting sites on beaches. Such destructive behavior is ecologically relevant as it could potentially damage restoration materials on restored shorelines, thus rendering them ineffective (National Park Service, 2021). Prior studies have observed vertebrate animals utilizing shoreline restoration sites in various capacities. For example, an earlier study on vertebrate interactions with shorelines reported North American Raccoons in high abundances along Florida's east coast (Rifenberg et al., 2021). This study concluded that none of the observed vertebrates, including *Sus scrofa* (invasive Feral Hogs) and North American Raccoons, negatively affected the shoreline or vice versa. Birds and other vertebrate species were observed foraging, mating, and benefitting from various ecosystem services along Canaveral National Seashore (CANA) shoreline sites (Rifenberg et al., 2021).

Rifenberg and colleagues (2021), among many other scientists, tracked vertebrate behaviors and abundances using wildlife trail cameras as their primary observational methodology. Such cameras provide an advantage in observing wildlife because they may directly record these populations with minimally intrusive contact after installation. This technology has been used in various studies, including those focused on *Herpestes urva* (Crab-eating Mongoose) and *Elephas maximus* (Asian Elephant) (Naing et al., 2015). Camera-based data collection benefits observers' time as they are efficient per reduced transportation and through the opportunity for remote observation. Other benefits include unlimited access to animals despite weather conditions and decreased disturbance to the animals' natural behaviors. Cameras also offer advantages by recording elusive or nocturnal animal activity (Trolliet et. al., 2014). Most importantly, wildlife cameras allow us to observe animal behaviors more completely as opposed to fragmented, manual observances with uncontrollable anthropogenic variables.

The CANA is located along the east coast of Central Florida; park management permitted our team to deploy

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numerous estuarine shoreline stabilization projects between 2011 and 2022. During this period, the University of Central Florida's Coastal and Estuarine Ecology Lab (UCF CEELAB) and their coastal community partners deployed a living shoreline restoration technique that utilized Naltex™ plastic mesh bags. The bags were filled with recycled oyster shells as a breakwater material and placed seaward of *Spartina alterniflora* (smooth cordgrass), *Rhizophora mangle*, *Avicennia germinans*, and *Languncularia racemosa* (mangrove species) (Fillyaw et al., 2021). In these locations, restoration was necessary to prevent further shoreline erosion caused by the loss of shoreline habitat from storms and boat wakes (Fillyaw et al., 2021). The studies on these restoration materials at nearby sites supported the optimistic conclusion that living shoreline methods successfully slowed the erosion and increased the shoreline habitat (Donnelly et al., 2017; Fillyaw et al., 2021). Likewise, Riffenberg et al. (2021) found no negative impacts of Naltex™ wave breaks on shoreline vertebrates, suggesting a positive future for this restoration method.

As of Spring 2021, all of UCF CEELAB's shoreline restoration deployments are fully plastic-free after a year-long transition to plastic-free materials (Walters et al., 2022). UCF CEELAB scientists are now testing various non-plastic materials to determine their effectiveness as breakwaters for living shoreline deployments. Specifically, they are testing breakwaters constructed from cement-infused, volcano-shaped jute structures and shell bags with similar dimensions to the previous plastic mesh bags. These living shoreline deployments are now made from aluminum coated with zinc, or "crab pot mesh," to complement this plastic-free, biodegradable material testing for shoreline restoration suitability. Amid these changes, one should ask how vertebrate animals are responding to the shapes and materials used in these new, biodegradable breakwaters. Our research team deployed wildlife trail cameras over 2 months (1 month for pre-restoration and 1-month for post-restoration) to compare plastic mesh shell bags, metal mesh bags, and cement-infused jute structures. Among these sites, we compared vertebrate abundances and their behaviors on these structures to positive control sites (intact shorelines) and negative control sites (highly eroded shorelines). A critical consideration throughout this observation period included tracking negative interactions between the vertebrates and living shoreline components, including plants and breakwater materials; I also noted any behaviors relating to the camera equipment.

METHODS

Living shoreline stabilization in the CANA occurred throughout May 2021, along 320 meters of shoreline, with equal distances covered by metal shell bags and cement-infused jute volcano structures (hereafter called "volcanoes"). In 2021, stabilization occurred immediately north of previous shoreline projects completed in 2019 and 2020, where all breakwaters consisted of Naltex™ plastic mesh bags. All shell bags (plastic, metal mesh) were filled with 3.8 liters of disarticulated oyster shells recycled from restaurants. The recycled oysters were quarantined in the sun for upwards of 6 months. The volcano frames were constructed from commercially purchased jute mesh soaked in quick-drying cement

Figure 1.
Restoration Materials.

Note. Jute-infused cement volcanoes (left), metal mesh oyster shell bags (middle), Naltex™ plastic oyster shell bags (right).

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that acted as a hardener. The individual structures were approximately 0.25 m in height and 0.35 m in diameter and weighed approximately 16 kg (~35 pounds) with a center hole that narrowly tapered toward the top. This design minimized the need for raw materials while providing stability in 25 mph winds and waves (MJD, pers. obs.).

To determine valuable data for the research goal, 18 sites were selected randomly along the CANA and remained constant throughout the study. Included in 3 of the sites were cement-infused jute volcanoes, another 3 had metal mesh shell bags, and 4 had plastic mesh shell bags (see Figure 1). An additional 8 sites served as positive and negative controls, with 4 per designation. The positive controls consisted of intact shorelines with vegetation that did not need stabilization; the negative controls were eroding shorelines that were neither restored previously nor restored during this study.

Figure 2.
The Bushnell "Trophy Cam HD" Wildlife Camera on a Mount at the Living Shoreline Site

Each of the 18 sites contained 1 motion-activated Bushell "Trophy Cam HD" wildlife camera placed by the UCF CEELAB team on camera mounts constructed from aluminum posts buried into the sediment for stability. We set each camera at angle that would show the restoration material and the shoreline (see Figure 2). The cameras were manually set to record continuous 10-second video clips upon detecting motion. The research team visited all 18 sites twice per month by boat to perform routine maintenance, which included checking if the camera was operational and replacing batteries and SD cards when necessary. On Day 1 (13 Apr. 2021), each camera was deployed with 1 SD card and 8 new AA batteries. The cameras were retrieved on 22 Jun. 2021 and contained 1 month of pre-restoration data and 1 month of post-restoration data.

Camera Analysis

I manually assessed all the videos to determine the vertebrate species' abundance, behaviors, and their interactions with shoreline materials. The abundances of vertebrate animals in this study was determined by counting the individual animals in each video clip and tallying the totals while categorizing each species. The separation of noted species were by "pre-restoration" and "post-restoration" categories for comparison. Where the same animal appeared to occur in multiple sequential video clips, we considered them an individual based on methods developed by Rifenberg et al. (2021). If 10 minutes or longer elapsed before an individual of the same species again appeared on camera, I tallied it as a new, unique individual. The videos also document vertebrate behaviors on all materials and their interactions with the camera setup.

Behavior Categorization

We reviewed the video content and sorted the footage into the following behavioral categories: foraging, walking, eating, standing, flying, and interacting with breakwater materials (walking on, foraging from, or damaging the materials). We also noted positive and negative interactions with the camera equipment. An animal's downturned mouth and slow, intermittent walking patterns indicated their foraging behaviors. By contrast, faster, more purposeful movement with no intermittent stops to look for food indicated walking behavior. Determining the vertebrates' eating behaviors required confirmed video footage of them purposefully chewing identifiable material in their mouth. Their

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Table 1.
The Abundance of Observed Vertebrate Species and their Abundances

Species Name	Common Name	Pre-restoration	Post-restoration	Total
Actitis macularius	Spotted Sandpiper	2	0	2
Anas platyrhynchos	Mallard Duck	1	0	1
Ardea herodias	Great Blue Heron	6	5	11
Arenaria interpres	Ruddy Turnstone	2	1	3
Cathartes aura	Turkey Vulture	8	7	15
Columbina passerina	Common Ground Dove	2	0	2
Didelphis virginiana	Virginia Opossum	2	1	3
Egretta tricolor	Tricolored Heron	6	8	14
Eudocimus albus	American White Ibis	1	1	2
Felidae rufus floridanus	Florida Wild Bobcat	5	4	9
Odocoileus virginianus	White-Tailed Deer	15	16	31
Procyon lotor	North American Raccoon	519	378	897
Sciurus carolinensis	Eastern Grey Squirrel	2	2	4
Sus scrofa	Feral Hog	29	20	49
Unidentified songbird		0	1	1

interactions with breakwater materials were labeled as positive and negative interactions. Positive interactions included walking on or directly foraging from the materials. Negative interactions differed from positive ones according to whether the vertebrate damaged or avoided the restoration materials. Destructive behaviors when interacting with the cameras were noted as negative interactions, while accidental behaviors, such as knocking into the camera, were categorized separately. Chi-squared tests were performed for all analyses to provide statistical conclusions relevant to the scope of the study.

RESULTS

Throughout the study, I observed 1,044 vertebrate individuals from 15 different species (Table 1). These observations indicate that the North American Raccoon had the most observations (897), followed by the Feral Hog (49). The least observed species was *Anas platyrhynchos* (Mallard Duck), with only 1 recorded observation captured on video. The shoreline observations were composed primarily of vertebrate mammals, followed by wading birds.

Statistical Analyses

The first tested null hypothesis posited the same vertebrate species abundance before and after the restoration of shoreline sites. This hypothesis returned a p-value less than 0.05 ($p < 0.0001$), thus rejecting the null hypothesis. Fewer animals were observed on the CANA shorelines during the month immediately after restoration than when compared to pre-restoration. Next, we separately compared the number of foraging observations of the North American Raccoon and Feral Hog pre-deployment and post-deployment of the restoration materials. Both cases rejected the null hypothesis of a similar number of foraging observations before and after restoration ($p < 0.0001$), suggesting fewer foraging observations post-restoration. Such a finding could indicate an anthropogenic effect of humans using the habitat for restoration practices, as the North American Raccoon and Feral Hog foraging observations were reduced by over an order-of-magnitude during the post-restoration period.

DISCUSSION

From April-June 2021, I observed 15 total unique animal species on living shoreline sites in the CANA. With 897 recorded observations (85.92% of the total), the North American Raccoon was the most abundant

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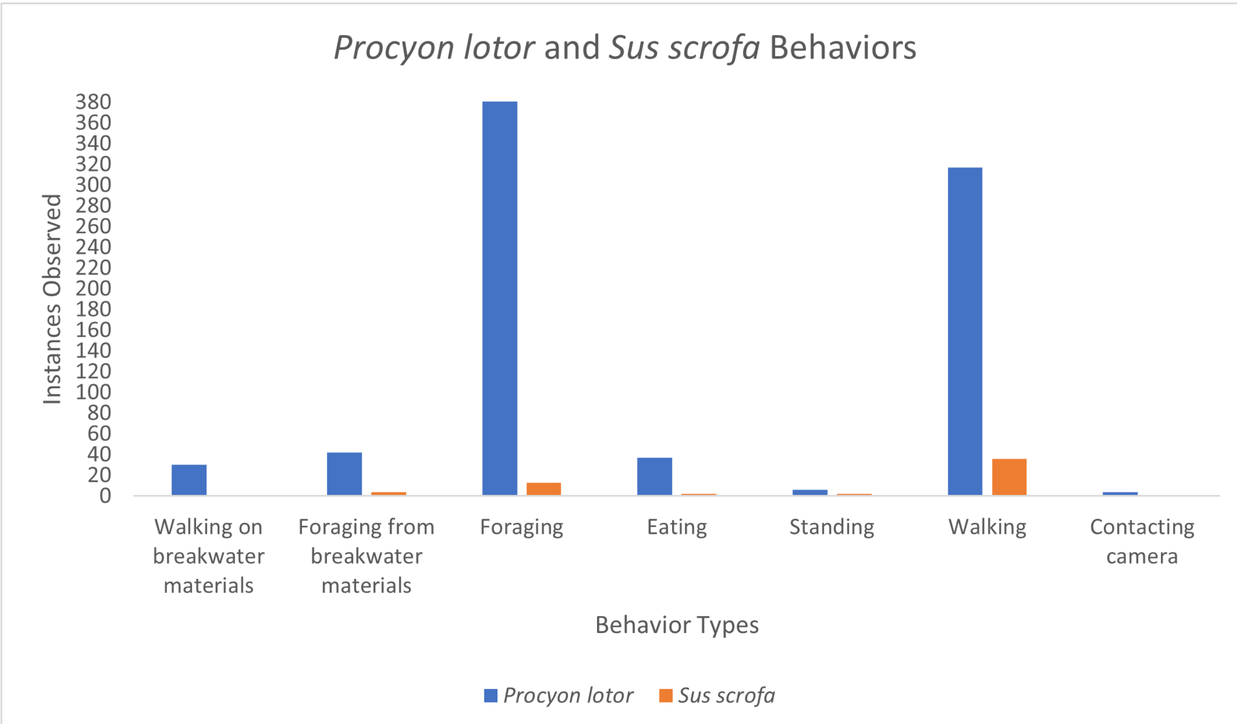
Figure 3.
Observed Behaviors of *Procyon lotor* (North American Raccoon) and *Sus scrofa* (Feral Hog) Before Restoration



mammal observed before and after restoration. With 8 observations (0.008% of the total), the *Cathartes aura* (Turkey Vulture) was the most abundant bird species recorded. The research team recorded only one unidentifiable songbird. Wading birds appeared on sandy shorelines and in the nearby water. And while the North American Raccoons were seen in the water, all other mammals, including the Feral Hog were recorded only atop breakwater materials or land and avoided entering the water. All vertebrate species exhibited foraging behaviors, most notably the North American Raccoon. The most common observed vertebrate behavior was foraging, exhibited primarily by the North American Raccoon. Swimming behavior was the least observed, recorded only for the Mallard duck. Our cameras enabled the team to observe recordings of all the mammals, day and night. The exception includes *Didelphis virginiana* (Virginia Opossum) and *Sciurus carolinensis* (Eastern Grey Squirrel), observed at night only. Vertebrate activity and abundance were monitored throughout all weather conditions during the data collection period, and a decrease in activity became noteworthy during instances of rain and severe weather. Most vertebrate species did not appear in rainy or turbulent weather conditions, except for the North American Raccoon and Feral Hog, both of which were observed during rain.

The North American Raccoon was seen using all types of shorelines as foraging sites, walking on the metal and plastic shell bags, and the cement/jute volcanoes (Figure 4). This species foraged more frequently on restored shoreline sites than negative control sites and more often on the 3 new breakwater materials than positive control sites. Further, the North American Raccoon and Feral Hog were the only animals who directly interacted with the camera throughout the observation period. The footage depicted the North American Raccoons looking at the camera and reaching for the camera casing; Feral Hogs seemingly encountered the camera accidentally by bumping into the camera's casing with their extremities while passing by the setup (Figure 3). This behavior was similar to results found for both species by Riffenberg et al. (2021). The use of restoration material as foraging sites (see Figures 3 and 4) suggests that these vertebrates are utilizing the new habitat features for their benefit, a promising find for the future of restoration activities along CANA shores and beyond.

In the CANA, the North American Racoon is one of the top predators in the food web, and have increasingly large

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populations due to a recent lack of natural predators; namely the *Puma concolor coryi* (Florida Panther) and *Canis rufus* (Florida Red Wolf) (National Park Service 2021). Another predator, *Felidae rufus floridanus* (Florida Wild Bobcat), was observed 9 times (0.008% of the total) during the study's visiting sites where all 3 restoration materials were deployed; whether these were 9 individuals or fewer with repeated sightings is unknown. The Florida Bobcat species has a shrinking population due to genetic isolation on Florida's eastern coast (National Park Service 2021). *Odocoileus virginianus* (White-Tailed Deer), was the third most observed mammal with 31 total observations (0.029% of the total) on our cameras in the CANA and is likely a growing population in the area due to the decreasing prevalence of predatory animals in the park, including those predators mentioned above (National Park Service, 2021).

The Feral Hog (49 observations, 0.047% of the total), is an invasive species in the CANA and was observed interacting with all 3 types of restoration material; this animal is responsible for habitat destruction within and throughout its range (L. Walters, pers. obs.). As a result, this species presents a large risk to native wildlife and habitat (Engeman et al., 2007). As they have established a breeding population in the CANA in recent years, Feral Hogs are responsible for reducing the population of native snakes and vegetation and present a substantial risk to Sea Turtle nesting sites (US Parks, 2021). A recent study concluded that the Feral Hog disrupts local ecosystems via resource competition, unnatural predation, and disruption of positive species interactions (Hensel et al., 2021).

Interactions with Restoration Methods

Vertebrate interactions with restoration materials varied greatly with the chosen restoration method. At sites restored with plastic mesh shell bags, vertebrates commonly used the material as a walking surface, and individuals were observed walking directly over the materials. Sites restored with cement-infused jute volcanoes and metal mesh shell bags were predominantly used as perching sites during foraging; the North American Raccoon and Feral Hog also made contact by walking over the materials. The North American Raccoon foraged from these materials more than other vertebrates, but *Eudocimus albus* (American White Ibis; a type of bird) and Florida wild bobcat were also observed utilizing materials as a foraging site. Vertebrate usage of these new breakwater materials as foraging sites is an important finding in this study and suggests that such restoration material does not inhibit animal behavior. Further, the research revealed no evidence that the vertebrates preferred to forage from breakwaters over natural materials (e.g., trees).

Throughout the study, no negative vertebrate interactions between vertebrates and restoration vegetation were observed. This observation is an important finding, as it indicates a lack of negative consequences or species disruption from deployed materials. No species removed branches, leaves, whole mangroves, or marshgrass from the shoreline sites. Among observed vertebrates, 3 species (the North American Raccoon, Feral Hog, and Florida Wild Bobcat) were recorded walking through mangroves with no observed damage. This finding is supported by

Figure 4.
The Observed Behaviors of *Procyon lotor* (North American Raccoon) on Different Restoration Materials

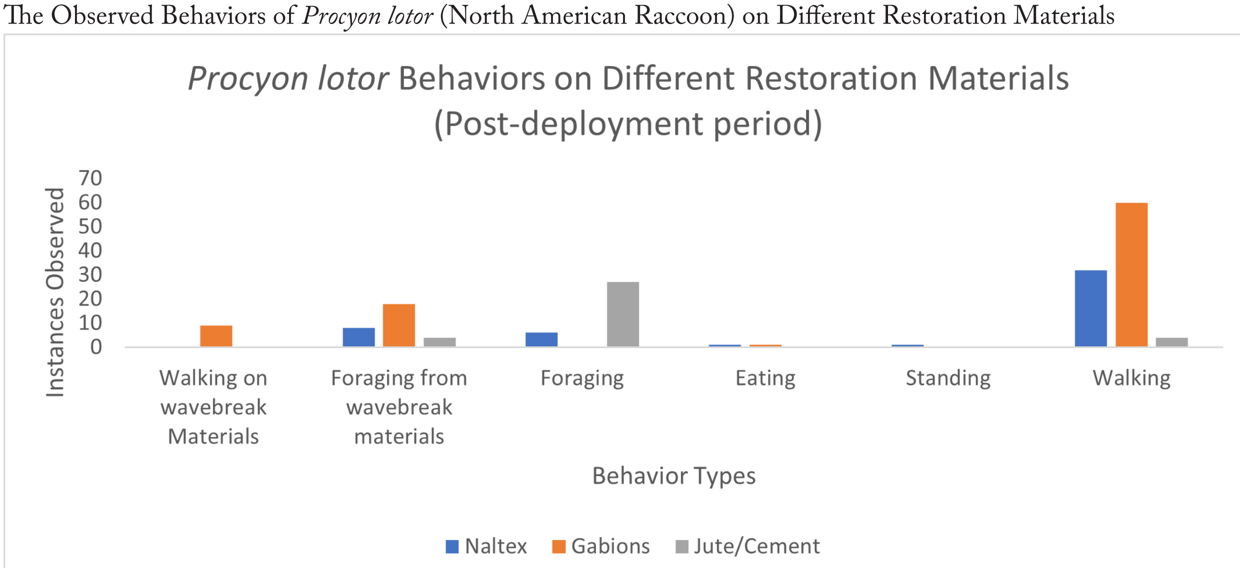

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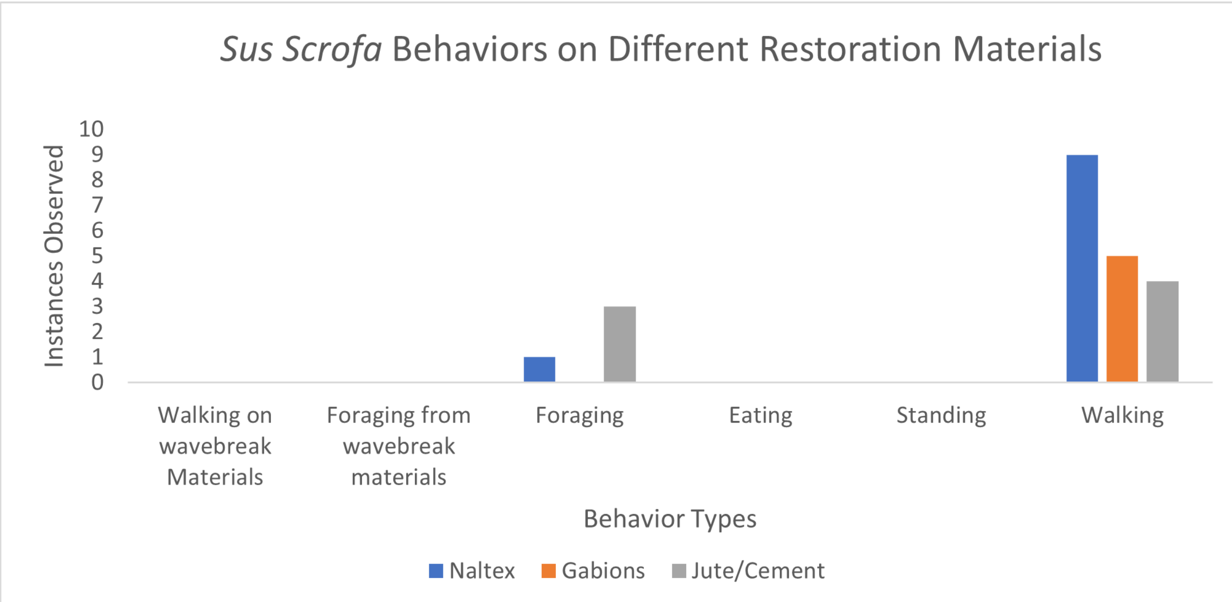
Figure 5.
The Observed behaviors of *Sus scrofa* (Feral Hog) on Different Restoration Materials.



previous UCF CEELAB studies that utilized motion cameras in the CANA (Riffenberg et al., 2021).

The vertebrate abundances along control shorelines were unequally split, with 514 observed vertebrates on negative (eroded) control sites and 167 observed on positive (vegetated) control sites. This dispersion could have been due to external factors not included or observed in the study, like varying levels of anthropogenic activity near these different sites. Alternatively, some species prefer to forage or rest on exposed, empty sites. The most abundant vertebrate species on both site types was the North American Raccoon, and the most abundant behavior recorded on both control shoreline sites was foraging.

CONCLUSION

This research suggests that the vertebrate animals occupying the estuarine shorelines of the CANA do not negatively interact with the tested restoration materials immediately during the post-restoration period. This study observed 1,044 individuals representing 15 species during this 2-month project. However, there were fewer individuals of all vertebrates, including the 2 most prevalent species (the North American Raccoon and Feral Hog), immediately following the completion of community restoration. There were no observed instances of negative interaction between the vertebrates and materials indicative of limited habitat disruption, and interactions between them were limited to camera disturbance.

Due to the nature of the study, several limitations should be noted. Using a remote recording process such as motion-activated cameras came with technical difficulties throughout the research. In areas with constant vegetative movement, the camera ran almost continuously, posing a higher risk of battery drain. Due to this limitation, one instance during the collection period resulted in a dead camera and a slightly more limited video library. Further, with continuously recorded videos, many recordings presented vegetative movement exclusively without the presence of vertebrates. As the SD card filled, the images were saved as photos rather than video clips, which posed a limitation when a vertebrate was present but could not be recorded in motion. Using photos to determine behaviors rather than videos may have led to inaccurate behavior classifications in a limited number of cases (< 5%), particularly if the behavior classification relied on movement patterns such as foraging and eating, using the criteria defined above. The methodology choice of recording vertebrates as one individual over a ten-minute period could have led to over or under-estimating vertebrate abundances.

However, using this methodology allowed us to have consistent, remote data as vertebrates moved around naturally without human interference, and the benefits

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provided to our researchers significantly outweighed this consideration. Throughout this study, vertebrate recordings on different days could have been the same individual but were separated in time or location and counted separately. For species with limited numbers in the CANA, such as Bobcats, some recordings may not have been indicative of the total number of vertebrates present. Furthermore, data collection occurred from April through June, entering the summer months, which tend to have higher levels of anthropogenic activity due to high rates of Florida tourism. Differing levels of anthropogenic activity with the seasons may occur throughout the year based on fish and crab harvesting permits and seasonal changes in tourism. Moreover, this study did not consider migratory seasons for these vertebrate species. A longer study period is needed to provide information to evaluate vertebrate activity and abundance throughout the year.

Continued observations are necessary for long-term conclusions to evaluate further the effect of the different restoration materials along the CANA as restoration material ages, and live oysters attach to the breakwaters. Furthermore, evaluating restoration material in areas of varying anthropogenic activity could be useful in indicating the best materials to use in differently frequented environments. Particularly in high tourist areas, longer studies could show an expected projection of reduced abundances and behaviors in correlation to increased anthropogenic activities. Additional research focused on the impact of these restoration materials in a variety of shoreline habitats would also be deeply beneficial to the field, providing a much broader selection of data not limited to the Florida coastal environment.

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