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Determination of the burrow shapes of *Cardisoma guanhumi* on Vieques, Puerto Rico

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ABSTRACT

Objective: To determine the burrow morphology of *Cardisoma guanhumi* and to determine if a battery-powered fiber optic camera could be used to investigate these burrows.
Methods: A portable fiber optic camera was used to investigate 116 active burrows. All burrows were categorized according to shape. The diameter of each burrow was also recorded and biomass calculations were completed at each study site.
Results: Analysis showed that different study sites were more likely to have particular burrow shapes than expected. Three main types of burrows were classified as horizontal slide, short and shallow, and inverted-S. A Pearson *Chi*-square analysis revealed that burrow shape was not equally distributed across study sites ($\chi^2 = 61.05$, $df = 18$, $P < 0.0001$). Biomass calculations showed that different sized animals inhabited different study sites (ANOVA; $df = 7$, $MS = 158.3$, $F = 13.9$, $P < 0.0001$). The fiber optic camera was useful in determining burrow morphology and occupancy non-destructively.
Conclusions: As the locations of juvenile individuals of this species are poorly known, and the species is both ecologically and economically important where it occurs, a greater understanding of burrow morphology and size segregation may help agencies be responsible for managing this natural resource to do so effectively.

1. Introduction

Vieques is an island-municipality of the Commonwealth of Puerto Rico and is situated 11 km off the southeast coast of the main island of Puerto Rico. Prior to 2001, all but the interior 1/3 of the island was used for military maneuvers and ammunition storage by the US Navy[1]. In 2001, this land was turned over to the Puerto Rico Conservation Trust, the municipality of Vieques and the Department of the Interior[1]. In 2003, the eastern navy lands were turned over to the Department of the Interior and management of this land to the United States Fish and Wildlife Service (USFWS). On May 1, 2003, Vieques became the largest US Wildlife Refuge in the Caribbean[2,3]. The refuge consists of approximately 7 300 ha of coastal and mangrove ecosystem and some of these areas have been open to the public[3]. Because of the Navy's activities, many of the island's 9 300 residents questioned that the bombing may have effects on marine ecosystems, in particular, the fish and land crabs which are important economic resources to the islanders. In 2005, the National Oceanic and Atmospheric Administration Office of Response and Restoration conducted studies involving the land crab, *Cardisoma guanhumi* (*C. guanhumi*), and the fiddler crab, *Uca* spp. to determine if explosive compounds, polychlorinated biphenyls, organochlorine pesticides, or heavy metals were present in quantities that could threaten human health or present an ecological risk. The study determined that there would be no harmful effects to human health from consuming land crabs from Vieques (National Oceanic and Atmospheric Administration, 2006).

C. guanhumi, locally known as "juey" or "cangrejo", are harvested as a food and income source in Vieques[4,5]. Currently, hunting of these crabs is only allowed seasonally within the Vieques refuge. Poaching practices have become widespread and problematic[5]. On the main island of Puerto Rico, overharvesting has resulted in significant declines in *C. guanhumi* population over the past forty years[6]. Today the overall body size of harvested crabs on the main island is smaller than those harvested from Vieques, likely as a result of the overharvesting[5]. USFWS on Vieques is faced with the task of preventing similar circumstances from occurring on Vieques. USFWS plans to open some of the refuge for crab harvest as part of their resource and land management 5-year plan. Their goal is to allow crab harvest from certain areas while leaving other areas undisturbed, thus protecting the crab population from overharvesting[5]. The locals on the island use *C. guanhumi* for food as well as an income supplement. Because of the increase in tourism on Vieques, the demand for fresh crab by local restaurateurs

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has increased. In addition, Vieques crabbers can sell their catch on the main island of Puerto Rico, as Vieques crabs are larger and more desirable at up to $45/kg in shell.

The goal of this research was to provide USFWS with information concerning the population, burrow morphology, and burrowing habits of the giant blue land crab, *C. guanhumi* in various burrow areas within the refuge. This information could then be used to develop sustainable hunting practices for the Vieques National Wildlife Refuge while managing the resource and preventing overharvesting.

The ability to determine if a burrow is occupied or unoccupied is important for rapid population assessment of a burrow area. According to Govender and Rodriguez-Fourquet[6], the presence of fecal pellets just outside the entrance of the burrow is indicative of occupancy. In this comparison study of trapping versus presence of fecal pellets, it was found that the presence of fecal pellets was significant in predicting population size when compared to trapping[6]. Gender of the crab can also be determined by the shape of the fecal pellets, with male pellets being oval-shaped and female pellets spherical[6].

Data collected during this research included such burrow dynamics as burrow shape, length, diameter and whether or not burrows were occupied by multiple residents. It is well-established that *C. guanhumi* burrows are excavated until groundwater is reached[7]. Because of their reliance on water for respiration to wet their gills, *C. guanhumi* can only live without water for a maximum of three days[8]. The burrow environment helps to reduce water loss by evaporation because the burrows are humid and there is a constant source of water at the end of the burrow[9]. How deep a particular burrow is excavated is determined by the depth of the water table[10,11]. Typical burrow shape begins shallow, at an angle between 25 and 50 for the first 30 cm then descends almost vertically[4,10]. Direction is sometimes dictated by obstructions encountered such as roots[10] or the burrow may be abandoned if digging conditions are not suitable. Burrow diameter is directly correlated with carapace width, thus size of crab occupying the burrow can be determined[11]. Crab size is an important variable in land management decisions because a given burrow area is usually occupied by similar-sized crabs[5]. As for burrow occupancy, it was once thought that there was only one crab occupying each burrow and only one opening for burrow access[12]. However, there is a conflicting report by Feliciano[4] that reported multiple occupants per burrow. Other studies questioned the number of entrances to the burrow by describing 'Y-shaped' burrows that had upper side chambers that were dry and the main burrow that led to the water table[10]. This study will help clarify if burrows in Vieques have similar burrow dynamics to other burrow areas previously studied. If *Cardisoma* on Vieques typically have only one occupant per burrow and each burrow has only one entrance, then the feasibility of using walk-through surveys of burrow areas can be evaluated. The goal of the research is to gain enough information about the burrow areas so that USFWS can track relative population numbers across the refuge. We hypothesize that crab burrow morphology and occupancy rate are both consistent across sites where they occur. We introduce a novel method examining burrows in a cost-effective and non-destructive way.

2. Materials and methods

C. guanhumi burrow sites located on the south-central coast of Vieques within the boundaries of the USFWS Vieques Wildlife Refuge were the focus of this study. Data collection was done between May 20 and May 30, 2011. Prior to data collection, a survey of twelve burrow sites was located by the researchers with the help of Vieques USFWS Biologist and Refuge Director Mike Barandiaran. From these twelve sites, 8 locations were chosen for data collection (Figure 1). Within these burrow sites, only active burrows were investigated in this study. An active burrow is defined as a burrow that has freshly excavated soil at the entrance and whose entrance is free of debris. Active burrows often have fecal pellets near the entrance[6]. The shape of the fecal pellet indicates the gender of the crab occupying a given burrow. Elongated, oblong pellets indicate male feces and spherical pellets indicate female feces[5]. Presence and shape of fecal pellets were noted for each observed burrow.

Upon entering a crab burrow site GPS location, weather, time of day, site description, and topography were recorded. Digital photographs document the microhabitat of each burrow area. Tables were constructed in advance for randomizing burrow sampling. A

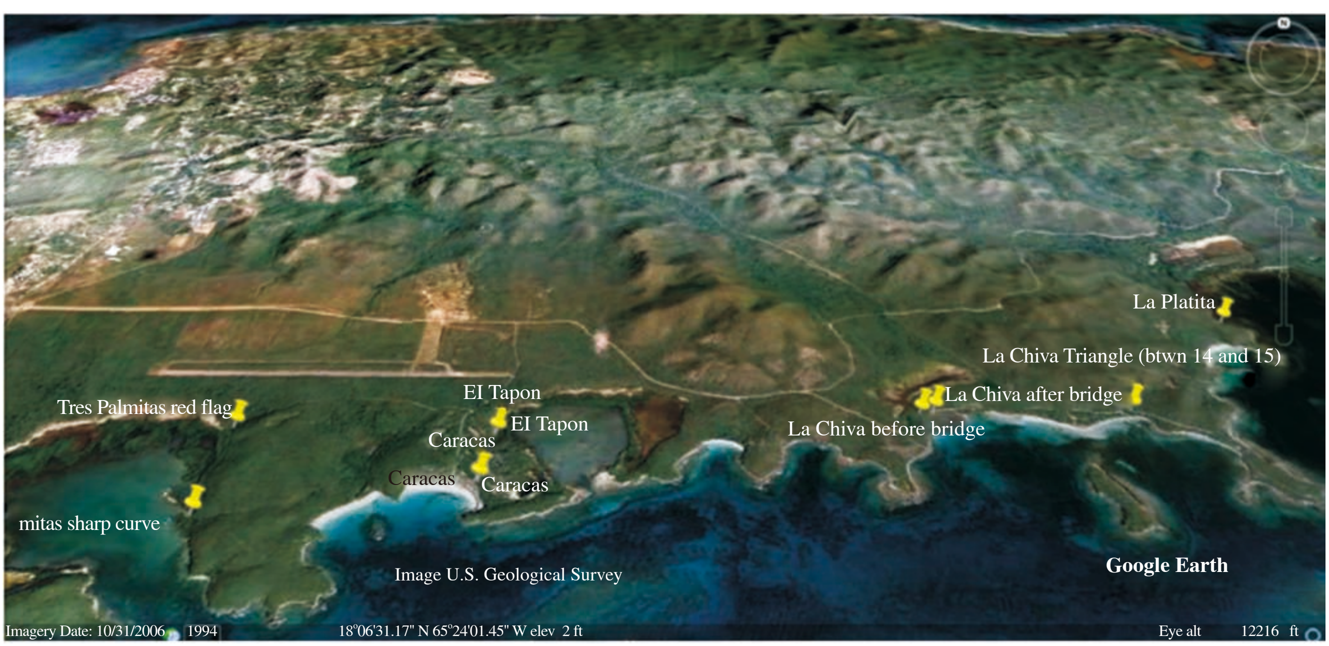

Figure 1. Map of data collection locations within the Vieques Wildlife Refuge, Vieques, Puerto Rico (Google Earth 2012).

list of random numbers between 1 and 360, for compass heading (1–360), and between 1 and 10 for steps taken were generated. The random degree heading from the data table indicated the direction from magnetic north in which to locate the first burrow. Next the number of paces from the data table determined which burrow to sample by pacing off the random number of steps in the direction of the compass heading. The closest active burrow was selected for sampling. This procedure was repeated for each burrow sampled. The diameter of each burrow entrance was measured in centimeters. Then a RIDGID micro Explorer (version 2.17) 20 mm fiber optic camera with a 0.92 m cable and a 1.83 m extension was used to collect data concerning burrow shape, occupancy, and length. The device was placed at the opening of the burrow hole and the cable was fed into the burrow completely, to determine burrow length and shape. The video display allowed for visualizing the inside of the burrow and the direction the camera took as it was pushed down into the burrow revealing the shape of the burrow. Burrow length was determined by measuring the length the cable used to reach the end of the burrow. Burrow occupancy was determined at the time of data collection by searching for the resident crab during each burrow examination. Approximately, 20 burrows per sampling site were randomly chosen for each burrow site sampled.

3. Results

A total of 165 burrows were examined for occupancy and burrow diameter, but because of heavy rains and flooding during data collection, only 116 of the 165 burrows were surveyed for morphology (shape) and length. Burrows were classified into three main morphological types: short and shallow, horizontal slide, and inverted-S. Rarely there were burrows that did not fit into these three main categories and were classified as "other shapes" such as forked and corkscrew.

Burrow morphology for the short and shallow type was a steep entrance that leveled off quickly and then traveled underground at a shallow angle until it reached groundwater (Figure 2). On beaches, we found this burrow type sometimes ended abruptly after a short distance. Crabs living in these burrows may get water from the ocean instead of their burrows. Horizontal slide burrows had entrances that began with approximately a 45° angle for approximately 50 cm then leveled off and continued for a distance of at least 50 cm until the tunnel would take a sharp turn and head downward at a 90° angle until the water table was reached (Figure 3). S-shaped burrows had a steep entry of 90° then turned level before curving back the other direction then finally straight down until groundwater was reached (Figure 4). There were a number of burrows that were catalogued as J-shaped tunnels, which may have actually been flooded S-shaped tunnels.

Figure 2. Burrow morphology for the "short and shallow" burrow shape. The entrance to the burrow is steep then gets less steep and then travels underground at a shallow angle until it reaches groundwater or ends. Occasionally the burrow would curve left or right. The water table is indicated by the scored lines at the bottom of the figure.

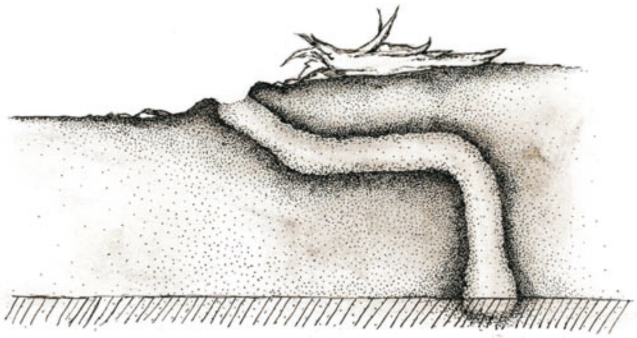

Figure 3. Burrow morphology for horizontal slide burrows started out their entrance with a steep angle then leveled off for a distance until the tunnel took a sharp turn downward at a 90 degree angle until the water table was reached.

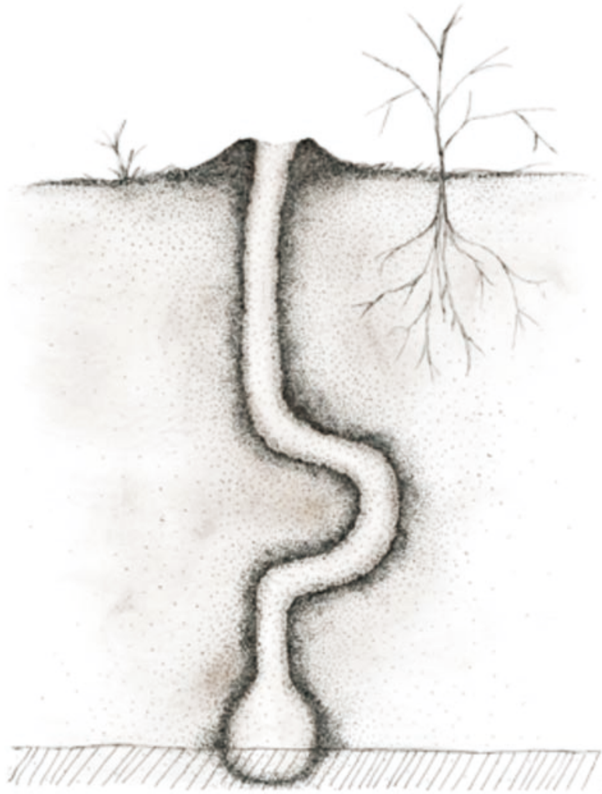

Figure 4. S-shaped burrow morphology had a characteristically steep entry of 90 degree then would level off before curving back the other direction then straight down again until groundwater was reached.

Mean burrow length for each burrow shape was determined with standard errors as well as mean length of burrows within each site. The Pearson *Chi*-squared analysis revealed that burrow shape was site specific ($\chi^2 = 61.05$, $df = 18$, $P < 0.0001$) and the null hypothesis stating there would be no difference between burrow shapes at different sites was rejected. Table 1 displays comparisons of shapes and lengths for each site.

A total of 165 burrows were surveyed for burrow diameter and occupancy. Data from Forsee and Albrecht[13] found a significant linear correlation between burrow diameter and crab size using the equation $y = 32.17 + 21(x)$; where y = crab mass (g) and x = burrow diameter (cm). Using the occupancy rate for each site, the total biomass surveyed was calculated. This information may be useful for the USFWS if they chose to continue to survey these sites for mean burrow width (and biomass calculation) as part of a monitoring program of the health of this species on the refuge. An ANOVA indicated that there were significant differences in biomass between the sites (*df* = 7, *MS* = 158.3, *F* = 13.9, *P* < 0.0001), rejecting the null hypothesis that there would be no difference in animal size between the tested sites. Differences seen could indicate that crabs of the same size burrow were at the same sites. Table 2 biomass displays the biomass estimates for *C. guanhumi*, based on burrow diameter and percent occupancy.

Table 1

Comparison of *C. guanhumi* burrow morphologies at study sites within the Vieques National Wildlife Refuge, Vieques, Puerto Rico.

Site	Sample size (*n*)	L-shaped (%)	Straight slide (%)	S-shaped (%)	Other shapes (%)	Length (cm) (Mean ± SE)
Caracas	19	32	10	37	21	100 ± 37.2
El Tapon	19	79	-	-	21	80.7 ± 18.5
La Chiva 1	20	60	-	40	-	86.5 ± 17.0
La Chiva 2	15	80	-	20	-	71.4 ± 9.9
La Chiva Triangle	9	44	56	-	-	72.0 ± 11.1
Tres Palmitas 1	15	80	-	20	-	68.8 ± 16.4
Tres Palmitas 2	19	63	16	10.5	10.5	55.3 ± 16.1
Total	116	63	11	18	8	-
Burrow length (cm) (Mean ± SE)	-	73.3 ± 6.8	96.9 ± 7.8	153.0 ± 4.0	-	-

Table 2

C. guanhumi biomass estimates based on burrow diameter.

Site	Burrow diameter (cm) (Mean ± SE)	Biomass estimate (g) (Mean ± SE)	Sample size (*n*)	Occupancy rate (%)	Biomass surveyed (g)
Caracas	18.1 ± 5.1	412.3 ± 107.1	20	25	2061.5
El Tapon	13.6 ± 2.5	317.8 ± 52.5	20	20	1271.2
La Chiva 1	12.3 ± 3.7	290.5 ± 77.7	32	69	6391.0
La Chiva 2	12.9 ± 3.5	303.1 ± 73.5	20	50	3031.0
La Chiva 3	11.5 ± 2.9	273.7 ± 60.9	20	65	3558.1
Tres Palmitas 1	14.4 ± 3.2	334.6 ± 66.7	20	40	2676.8
Tres Palmitas 2	10.1 ± 1.6	244.3 ± 44.1	20	35	1710.1
La Platita	8.8 ± 3.6	200.2 ± 58.8	13	77	2002.0

4. Discussion

This study found that *C. guanhumi* constructs burrows of different shapes in a consistent manner. This may be based on substrate type, depth to water, or other factors not captured in this study. The burrow type information combined with the biomass estimation may inform USFWS where younger, or at least smaller, crabs are tending to burrow. This information may also indicate where larger animals tend to burrow. In turn, this may help manawdgers such as USFWS determine what areas will be open for hunting, and which areas are not. This study also expands on the question of where the juveniles of this species burrow, as this has not been well understood[14]. A greater understanding of where young and older *C. guanhumi* are located will help with management of this important coastal mangrove animal which has been called a keystone species in this ecosystem[15].

The use of an inexpensive fiber optic camera has been useful in determining burrow morphology specific to the refuge area on the island of Vieques. Previous work on burrow morphology has been invasive and detrimental to the burrow occupants, with the use of plaster castes for instance[14]. Advantages of the camera were evident in the ability to be able to photograph and video-record animals. The camera is also waterproof and durable. The camera could be useful in studies with other species and in other locations. In addition, the camera had a rechargeable battery, lasting up to 12 h in the field. This camera may have a number of applications for the study of small animal burrows, as it provides illumination, flexibility, durability, and documentation using still shooting or video recordings.

Conflict of interest statement

We declare that we have no conflict of interest.

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