# *Promoting Biodiversity in a Pinch*

## The Influence of a Hawaiian Coastal Refuge on Ghost Crab (Ocypodidae) Size and Density on O'ahu, Hawai'i

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Biology 499 (OPIHI Internship) & Honor's Program Research Thesis
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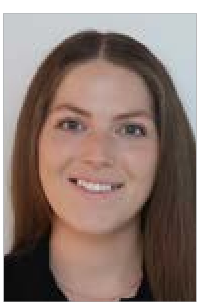
*In an effort to preserve ecosystem biodiversity, marine protected areas (MPAs) are established following governmental regulations. To better understand the significance of the refuge, ghost crabs (genus* Ocypode*, Hawaiian name Ōhiki), which tunnel deep into the sand and leave behind burrow holes, were used as an indicator species. The goal of this research was to compare the size, abundance, and density of ghost crabs inside and outside of James Campbell National Wildlife Refuge (JCNWR) to test the hypothesis of the success of beach biota from conservation. First, the sandy locations along the site were mapped using a GPS, then transects were randomized both inside and outside JCNWR. Within each transect, the burrow holes were counted, and the diameters were measured to estimate body size and abundance. The total number of burrows per unit area was used to calculate population densities. The results show no significant difference in ghost crab size or density inside versus outside the refuge. The results suggest the refuge is experiencing possible disturbance or the "spillover effect" providing protection to adjacent areas. Ultimately, the findings from this research can aid in conservation efforts at JCNWR to better protect the terrestrial crab.*

Biodiversity loss is among one of the greatest contemporary threats towards ecosystem function and human well-being. Anthropogenic (human-caused) disturbances including climate change, habitat fragmentation, ocean acidification, and many others are primary causes of this loss (Lee et al. 2015). In the effort to preserve biodiversity, marine management systems including marine protected areas (MPAs) are put in place following governmental regulations. There are various marine management systems in place around the world including marine sanctuaries, estuarine research reserves, ocean parks, and marine wildlife refuges. These MPAs share the goal of conservation, management, and protection of the marine habitat (NOAA 2018). A wildlife refuge is a coastal area protected and managed by the U.S. Fish and Wildlife Service (U.S. Department of the Interior 2019) with the mission to conserve, manage, and restore fish, wildlife, and plant resources and their



My name is Jessica Tritsch and I graduated with a bachelor of science in Marine Biology in Spring of 2021. This research was conducted in the OPIHI Internship, which is a citizen science program, and fulfilled my Honors Program Requirements at University of Hawai'i at Mānoa. Within this internship program, I had the opportunity to learn more about the impact that a Marine Protected Area (MPA) has on the inhabiting beach biota. I conducted this study at James Campbell National Wildlife Refuge, located on the North Shore of O'ahu. I can't wait to use the skills I learned from this research experience in graduate school and my future marine science career.

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habitats for the benefit of the American people (U.S. Fish and Wildlife Service 2019) by reducing the impact of heavy human activities, especially fishing, on key natural resources (Colléter et al. 2014). Wildlife refuges can benefit not only species within their borders but also those in adjacent areas through what are known as "spillover effects". The areas surrounding the protected region may serve as additional habitats for endangered species (Forcada et al. 2009). Because wildlife refuges aim to broadly benefit ecological communities it is appropriate to monitor their effectiveness through directly studying individual marine species that inhabit them.

The MPA assessed in this study was James Campbell National Wildlife Refuge (JCNWR), located on the North Shore of O'ahu, Hawai'i (Figure 1). The refuge was established in 1976 and was expanded in 2005 in order to support wildlife, including nine endangered Hawaiian waterbirds, migratory shorebirds, waterfowl, seabirds, mammals, and reptiles. Most importantly, the refuge focuses conservation efforts towards the threatened and endagered species listed by State and Federal governments (U.S. Fish and Wildlife Service 2013).

Data was collected both in JCNWR and the adjacent Kahuku Golf Course and Turtle Bay Resort. The adjacent areas both feature golf courses which can be particularly hazardous to the oceanic environment in numerous ways including the use of large quantities of water, run-off pollution, and the clearing of large amounts of land which often displaces native habitat (Leight et al. 2005). In between these golf course locations, the refuge is closed to the public, and therefore limited to human traffic, resulting in fewer human disturbances.

To assess the effectiveness of the refuge, ghost crabs (genus *Ocypode*, Hawaiian name Ōhiki), were used as an indicator species to infer the conditions of the habitat. Invertebrates are often used as indicator species as they are sensitive to anthropogenic disturbance (Pelletier et al. 2010; Arimoro and Keke 2017). Ghost crabs are semi-terrestrial crabs that live in sandy habitats along the high-tide mark or swash line and have the important ecological role of being an apex invertebrate predator. The burrow holes provide a fundamental shelter to the ghost crabs for protection from predators, climate, and vulnerability during molting and maternity. These burrow holes are clearly visible on shore and allow for easily acquired estimates of the density of active ghost crabs at a particular location. The ghost crabs represent one of the many important marine inhabitants that have significant ecological and economic impacts. A few of the functions provided by ghost crabs include having a key role in the filter-feeding food chain, feeding on organic matter and detritus, and supporting energy transfer (Fisher and Tevesz 1979).

The ghost crab population metrics were compared inside and outside of the wildlife refuge, that is respectively "closed" and "open" to human traffic, for the purpose of inspecting possible disturbance effects on beach biota and the success of the protection afforded by the refuge. Furthermore, ghost crab population metrics have been measured in previous years and that data was used to compare any changes occurring with time. Ghost crab density correlates with human traffic impacts on other biota, for example the endangered and endemic Hawaiian stilt bird whose diet consists of aquatic invertebrates (U.S. Fish and Wildlife Service 2013). The predicted observation was higher densities of ghost crabs, particularly those of


Figure 1. Satellite imagery of the field site, located on O'ahu, Hawai'i. The GPS mapping took place from Kahuku Golf Course (south) to Turtle Bay Resort (north), inclusive of the marine protected area—James Campbell National Wildlife Refuge and adjacent shorelines. Satellite imagery courtesy of Google Earth.

smaller size, inside the refuge. This prediction is based on the protection provided by the refuge compared to the lack of protection in adjacent areas with high volume of human traffic. The smaller ghost crabs, juveniles, require more access to the water and therefore are expected to be seen in the refuge where there is little disturbance. The larger ghost crabs might appear with equal frequency outside the refuge as they can hide in the burrow holes for longer periods of time compared to the juveniles. The difference could yield a lower average size of crabs in the refuge indicative of occupancy of that habitat by the full range of age classes.

This investigation contributes to the U.S. Fish and Wildlife Service's efforts to better understand James Campbell's impact on the Hawaiian coastline that is surrounded by human populated areas. Furthermore, understanding the health of ghost crabs, an important food source for the endangered Hawaiian shorebirds and the only endemic land crab at the refuge, can strengthen the overall conservation efforts at JCNWR. The monitoring of natural resources and ecological impacts of human disturbance are rare on the sandy shores and more research in this area is needed (Lucrezi et al. 2009). Examining the effectiveness of a refuge can therefore provide information useful in better developing policy and management strategies for the many MPA's in locations all over the world.

## Methods

### Beach Mapping

To begin, the field site was mapped using a GPS to mark the start and end points of the sandy locations inside and adjacent to James Campbell National Wildlife Refuge (JCNWR), as these areas are highly variable due to seasonal wave action. The coordinates were then mapped using QGIS software and Google Earth to determine the total habitable sandy beach area for ghost crabs inside and outside the reserve. The number of belt transects was calculated by dividing the total length of habitable shoreline by the amount of time it takes to complete a single transect (10–12 minutes), adding in sufficient time to transit between transects per field day. The total number of transects randomized at the sandy sections summed to 35 (T00–T34). Transects were spaced randomly in designated sandy areas, however each sandy area had a minimum of at least two transects and transects had to be at least 5 meters apart from each other (Figure 3). An equal number of transects were designated inside and outside the reserve for a balanced sampling design.

### Ghost Crab Population Surveys

Within these sandy locations, a belt transect (width of 5 m and variable lengths) was demarcated using survey flags. The length of the 5 m belt transect was marked using stakes, start-

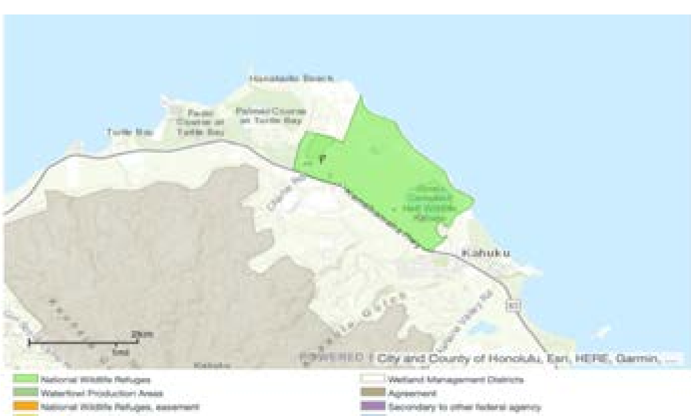


Figure 2. The map shows James Campbell National Wildlife Refuge highlighted in green and the adjacent Turtle Bay Resort and Kahuku Golf Course. The ghost crab surveys extended from Turtle Bay Resort, inside the refuge, and ended at Kahuku Golf Course. This map was retrieved from U.S. Fish and Wildlife Service website https://www.fws.gov/refuge/James_Campbell/map.html.


Figure 3. The GPS coordinates were used to map the sandy habitats inside and outside the refuge. This satellite image shows the locations of the transects that were surveyed for ghost crab population. Satellite imagery courtesy of Google Earth.

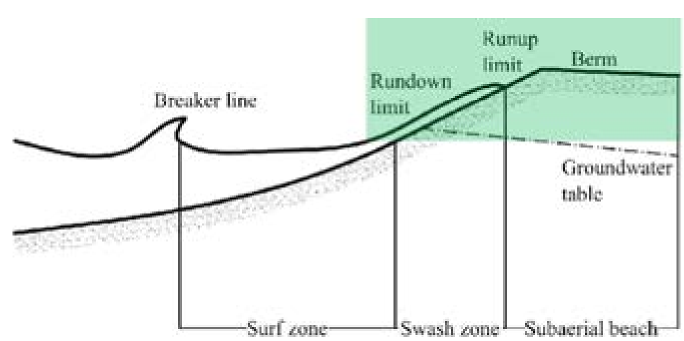


Figure 4. Beach zonation for ghost crab surveys will be conducted in the swash zone and subaerial beach (shaded green). Belt transects will be 5 m wide and of variable lengths (starting at the lower swash zone and ending at the last observable active burrow in the berm).

ing at the swash zone line (upper limit of the surf zone) and ending in the berm (at the last observable burrow). The distance from the swash line to the start of vegetation was measured and this gave the unit area of the survey zone (Figure 4). In order to measure the population density of ghost crabs per belt transect, abundances were divided by transect area. The active burrow hole diameters were measured to estimate body size of ghost crabs, whereas the total number of active burrows per unit area were used to calculate population densities inside and outside the refuge. This survey method for ghost crabs had limitations including burrow holes being disturbed before being accounted for and the sandy locations being limited inside the reserve as rocky habitats were more abundant.

### Data Analysis

Mean ghost crab population density and body size were compared between transects inside and outside the reserve using a two-tailed t-tests in Excel. Ghost crab population density and size were further analyzed running an ANOVA in R for analyzing among the previous years' data (2019–2021).

## Results

### Ghost Crab Density

The first of the results compare the density inside and outside the refuge in 2021, which represents the number of individual ghost crabs that are present in the measured area of each transect. The mean density outside (0.23 +/– 0.05) of JCNWR was not significantly different than the mean density inside (0.19 +/– 0.03) (t-test: t = 2.04; df = 31; p = 0.70, Figure 5).

Ghost crab density inside vs. outside over the last few years (2019–2021) differed significantly (GLM; Chisq=8.4, df=1, p=0.004, Figure 6). In 2019, data was not collected outside the refuge zone.

The final comparison of mean ghost crab densities was all ghost crabs, including counts from inside and outside the refuge, to give the total individuals per square meter. This shows a significant decline in overall ghost crab density driven by year (GLM; Chisq=17.4, df=2, p<0.001, Figure 7).

### Ghost Crab Size

Mean body size of ghost crabs, indicated by burrow size, inside the refuge (1.39 +/– 0.09) and outside the refuge (1.55 +/– 0.09) did not differ significantly (t-test: t = 1.96; df = 583; p = 0.219, Figure 8).

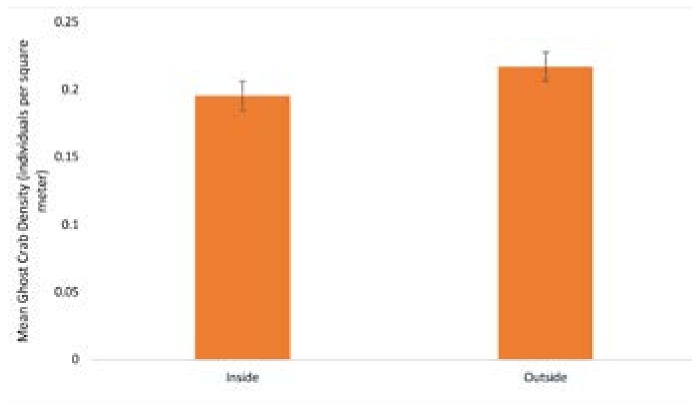


Figure 5. Mean ghost crab density (individuals per square meter) inside (0.19 +/– 0.03) compared to outside (0.23 +/– 0.05) the refuge. The mean ghost crab density does not give a significant difference in reference to location (t-test: t = 2.04; df = 31; p = 0.70).

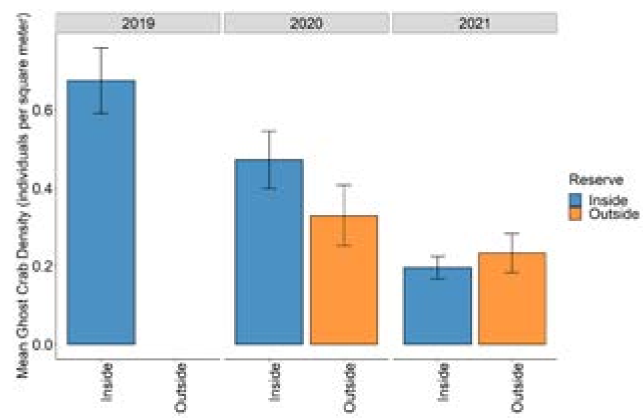


Figure 6. Mean ghost crab density (individuals per square meter) show significant difference between refuge status (inside vs. outside) being driven by years (GLM; Chisq=8.4, df=1, p=0.004).

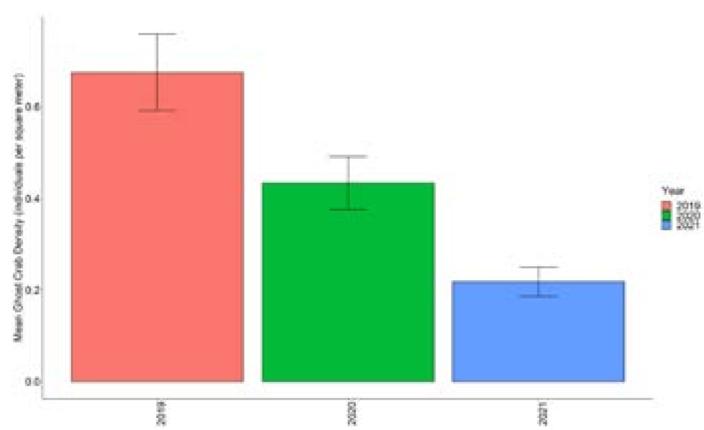

Figure 7. Ghost crab density (individuals per square meter) in comparison to year (2019–2021) showing a significant decline over time (GLM; Chisq=17.4, df=2, p<0.001). The highest ghost crab density is seen in 2019 and the lowest ghost crab density is in 2021.

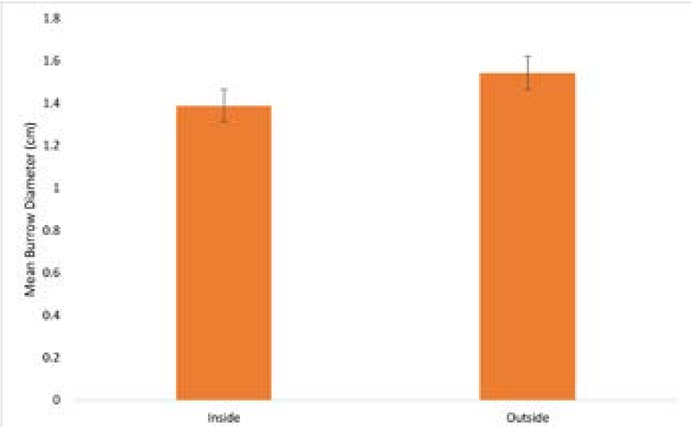


Figure 8. Mean burrow diameter of ghost crabs, representing size, inside vs. outside the refuge. The results show that the mean inside (1.39 +/− 0.09) compared to outside (1.55 +/− 0.09) does not show a significant difference (t-test: $t = 1.96$; $df = 583$; $p = 0.219$).

## Discussion

Ghost crabs (genus *Ocypode*, Hawaiian name Ōhiki) were used as an indicator species to capture the success of conservation efforts to limit disturbance of beach biota inside a refuge in comparison to outside the refuge at JCNWR. This model species is known to be vulnerable to disturbance, making it a suitable indicator species to represent beach biota as a whole, and since the burrow holes are typically inhabited by only the individual that dug them, examination of these can provide an effective indirect population assessment (Moss and McPhee 2006).

The results suggest that there is little to no difference between the inside and outside refuge when looking at ghost crab population metrics. One possible explanation for this is considering the "spillover effect", which is the beneficiary of increased biodiversity in areas adjacent to the protected region. This benefit is due to the migratory of protected species "spilling" into the adjacent habitats. MPAs are often put in place in areas of high fishing activity for instance, to increase fish populations as adult, juvenile, pelagic egg, and larvae are moving into the nearby areas (Colléter et al. 2014). Another way the spillover effect increases biodiversity is through the protection itself promoting an increase of species biomass and these animals migrating into the nearby areas. Though, there is limited amount of research on the quantification of the spillover effect and the assessment may take an extension amount of time to analyze as populations recovery and biomass grows (Lenihan et al. 2021).

The ghost crab population densities between the years (2019–2021) did show significant results of a decline in ghost crab density inside the refuge. A possible reason for this decline is the change in habitat dynamics inside the refuge. The ghost crabs thrive in habitats that are sandy to make burrow holes and have easy access to the water. This year in 2021, the GPS mapping of sandy locations revealed the lack of sandy regions compared to the abundance of sand outside the refuge. Sandy habitats are adaptive to the changes in environmental conditions and sand moves by various drivers within climate change including tides and sea level. The loss of sandy habitats can shift the ecological community and lead to coastal erosion. To protect sandy habitats, there are a few defensive mechanisms including the sand nourishment technique which replenishes the lost sand by adding sand that came from another location (Hanley et al. 2014). The ghost crabs may be slowly moving outside the refuge, following the movement of sandy habitats. This is an important phenomenon for JCNWR to monitor as ghost crabs are an essential food source for the endangered shorebirds being protected at the refuge.

The refuge was first established in 1976 efforts to protect the endangered Hawaiian waterbirds. Additionally in 2005, the conservation expanded to other birds including habitat protected for waterbirds, shorebirds, waterfowl, and seabirds. The abundance of protected predatory birds may have an impact on the decline of ghost crabs inside the refuge. The common birds seen at James Campbell often feed on the ghost crabs (U.S. Fish and Wildlife Service 2013).

Another challenge causing displacement of native plants and animals in Hawai‘i are invasive species. Invasive species are introduced often through human activities, making islands vulnerable to the invasion because island communities often require the use of shipping resources from another location. A common threat to the native species at JCNWR is invasive yellow crazy ants, *Anoplolepis gracilipes*, which may be having an impact on the ghost crab population metrics inside the refuge. Ants commonly monopolize the biological competition by forming in such large colonies. These yellow crazy ants are atypical in the way they forage, as they do not form trails and seem to have a lack of direction. This invasive ant species is seen all around the world, including Christmas Island where they have been studied and found to kill the red land crabs (Abbott 2005). The ants have a unique mechanism for capturing prey which is by spraying formic acid which weakens the response of the prey. Using this technique, they have been seen to capture birds and mammals in Hawai‘i (Plentovich et al. 2018). The presence of invasive yellow crazy ants may be a large concern for the refuge if the yellow crazy ants are preying on the endangered bird species themselves and their food resource, which are the ghost crabs.

This research did have limitations such as only studying one indicator species, the ghost crabs. Measuring the population metrics of other species in the same habitat, including inside and outside the refuge, may provide information on the ecological health all in all. This research can be replicated for other crustaceans including the mole crabs commonly found in this location. Furthermore, the Hawaiian shorebirds that reside in the refuge can be have a population assessment each year to see if there is a correlation with ghost crab population metrics. Urgently, the refuge may need to focus on the invasion of yellow crazy ants that may be dominating the sandy habitat and preying upon the ghost crabs inside the refuge, and possibly even the shorebirds as seen in other studies. Other research suggests the ghost crab population shift can be the result of the watermark on shore. Ghost crabs are found to decrease as the distance to travel to the water increases and this trend has been seen in locations around the world (Moss and McPhee 2006). The change in water height along the side is a factor that may correlate to sandy habitat loss inside the refuge.

Along with only focusing on one species, there were physical limitations in collecting data at transect locations including the general public sitting and/or walking in study site. This limited those regions from being analyzed and the transects had to be moved slightly to account for public occupying the exact transect location. Likewise, pets were commonly found running along the sand, possibly disturbing ghost crab burrow holes that had yet to be measured. This direct traffic along the beach causes disturbance of burrow holes, manipulating our data by the lack of active burrow holes accounted for or may be a factor in the population metrics of ghost crabs overall.

Ultimately, the results of this research did not show support of a difference in ghost crab population metrics when comparing inside vs. outside in the year of 2021. Though, the analysis did have concluding results that express a decline in ghost crab population densities inside the refuge along the years. The conservation of biodiversity is essential for ecosystem function and human health. Every species plays an important role in fulfilling an ecological niche. Governmental regulations at MPAs are critical as they have the capability of promoting increased biodiversity and species biomass in areas of high disturbance. Therefore, monitoring the success of these protected areas can provide information to strengthen regulations at current MPAs, as well as provide insight on where additional MPAs should be established.

## References

(2013) About the refuge. James Campbell National Wildlife Refuge. U.S. Fish and Wildlife Service. https://www.fws.gov/refuge/James_Campbell/about.html

(2019) Celebrating National Wildlife Refuges. https://www.doi.gov/blog/celebrating-national-wildlife-refuges

(2020) Marine Areas, Islands and Coasts | U.S. Fish and Wildlife Service. https://www.fws.gov/refuges/about/public-lands-waters/marine-coasts-islands/

Abbott KL (2005) Supercolonies of the invasive yellow crazy ant, Anoplolepis gracilipes, on an oceanic island: Forager activity patterns, density and biomass. Insectes Soc 52:266–273

Arimoro FO, Keke UN (2017) The intensity of human-induced impacts on the distribution and diversity of macroinvertebrates and water quality of Gbako River, North Central, Nigeria. Energ Ecol Environ 2:143–154

Colléter M, Gascuel D, Albouy C, Francour P, Tito de Morais L, Valls A, Le Loc'h F (2014) Fishing inside or outside? A case studies analysis of potential spillover effect from marine protected areas, using food web models. Journal of Marine Systems 139:383–395

Fisher JB, Tevesz MJS (1979) Within-Habitat Spatial Patterns of Ocypode quadrata (Fabricius) (Decapoda Brachyura). Crustaceana Supplement 31–36

Forcada A, Valle C, Bonhomme P, Criquet G, Cadiou G, Lenfant P, Sánchez-Lizaso JL (2009) Effects of habitat on spillover from marine protected areas to artisanal fisheries. Marine Ecology Progress Series 379:197–211

Hanley ME, Hoggart SPG, Simmonds DJ, Bichot A, Colangelo MA, Bozzeda F, Heurtefeux H, Ondiviela B, Ostrowski R, Recio M, Trude R, Zawadzka-Kahlau E, Thompson RC (2014) Shifting sands? Coastal protection by sand banks, beaches and dunes. Coastal Engineering 87:136–146

Lee J-H, Lee M-J, Lee G-G (2015) National level assessment of Biodiversity importance — Focusing on South Korea. KSCE J Civ Eng 19:46–62

Leight AK, Scott GI, Fulton MH, Daugomah JW (2005) Long Term Monitoring of Grass Shrimp Palaemonetes spp. Population Metrics at Sites with Agricultural Runoff Influences. Integr Comp Biol 45:143–150

Lenihan HS, Gallagher JP, Peters JR, Stier AC, Hofmeister JKK, Reed DC (2021) Evidence that spillover from Marine Protected Areas benefits the spiny lobster ( Panulirus interruptus ) fishery in southern California. Scientific Reports 11:2663

Lucrezi S, Schlacher TA, Walker S (2009) Monitoring human impacts on sandy shore ecosystems: a test of ghost crabs (Ocypode spp.) as biological indicators on an urban beach. Environmental Monitoring and Assessment; Dordrecht 152:413–24

Moss D, McPhee DP (2006) The Impacts of Recreational Four-Wheel Driving on the Abundance of the Ghost Crab (Ocypode cordimanus) on a Subtropical Sandy Beach in SE Queensland. Coastal Management 34:133–140

NOAA. What is a marine protected area? National Ocean Service website, https://oceanservice.noaa.gov/facts/mpa.html, 6/25/18.

Pelletier MC, Gold AJ, Heltshe JF, Buffum HW (2010) A method to identify estuarine macroinvertebrate pollution indicator species in the Virginian Biogeographic Province. Ecological Indicators 10:1037–1048

Plentovich S, Russell T, Fejeran CC (2018) Yellow crazy ants (Anoplolepis gracilipes) reduce numbers and impede development of a burrow-nesting seabird. Biol Invasions 20:77–86