HIGH SCHOOL EDITION
Journal of Student Research

Volume 12 Issue 2 (2023)

Population Dynamics of Intertidal Resident Species During a Reduction in Asian Shore Crab Population

Ryan Fernandez[1] and Alejandro Victoria[#]

[1]Mamaroneck High School
[#]Advisor

ABSTRACT

Hemigrapsus sanguineus (Asian shore crab), which is native to coastal estuarine habitats along the east coast of Asia, have overtaken a wide range of the coast in the northeastern region of the United States. Intertidal population densities of *Hemigrapsus sanguineus*, *Cancer irroratus* (Atlantic rock crab), *Littorina littorea* (Common periwinkle), and *Modiolus demissus* (Atlantic Ribbed Mussel), among others, were measured at three sample sites from 8/2/22 to 11/14/22 using quadrat sampling techniques. A period of removal was enacted solely upon Sample site #1 from 9/28/22 to 11/2/22 to cause a reduction in the Asian shore crab population. During the period of removal, no statistically significant changes in Asian shore crab demographics (Carapace size/sex ratios) would be observed ($p = 0.181$ for carapace size changes). There would however be an 8% decrease in Asian shore crab population density within Sample site #1, comparative to a 1% increase at Sample site 2. Rock crab population density at Sample site #1 would increase by a relatively drastic 31%, whereas the Rock crab population would experience only a 7% increase at Sample site #2. The Shannon-Weiner diversity index was used to derive the effective number of species (ENS). There would be a drastic difference in change of ENS following the removal period at Sample site #1 (increase of 0.248 ENS), and the change of ENS at Sample site #2 (decrease of 0.024 ENS), suggesting the reduction in Asian Shore Crab population played a role in increased population diversity of intertidal resident species.

Introduction

Invasive species have been successful in embedding themselves in numerous alien environments and continue to be important drivers of ecological change (Didham et al. 2005). These invasive species often make their host environment less suitable for native species and thus have the potential to be a significant contributing factor in the extinction of native species (Gurevitch & Padilla 2004, Clavero & García-Berthou 2005).

The Asian shore crab, *Hemigrapsus Sanguineus,* while native to coastal habitats along the east coast of Asia, have overtaken a wide range of the coast in the northeastern region of the United States as far north as Maine and as far south as North Carolina since its recorded arrival to the United States on the southern New Jersey coast in 1988 (McDermott 1991). Shortly thereafter, their presence was reported in the Long Island Sound in 1994 (McDermott 1998). Similar to numerous other recorded invasive species, the Asian shore crab's arrival has caused a multitude of problems regarding native species population levels as native prey species often decline in both diversity and abundance following the arrival of Asian shore crabs (Lohrer & Whitlatch 2002). In a Western Long Island Sound Estuary, declines of 50-90% in resident crab population levels were shown to coincide with a drastic increase in the population levels of Asian shore crabs over a span of 8 years (Kraemer et al. 2007). These drastic declines in resident crab population levels occur as a result of the invasive Asian shore crab outcompeting resident crabs in a variety of factors, such as higher fecundity, superior competition for space and food, release from parasitism, and direct predation on co-occurring crab species (Epifanio 2013).

There is a multitude of scientific literature documenting the impacts of *H. sanguineus* on native species, such as Epifanio 2013, Lohrer & Whitlatch 2002, and Kraemer et al. 2007. However, there is little documentation regarding the effects of a decreasing Asian shore crab population on native species, and nothing regarding how native species recover after Asian shore crabs have been eradicated from their foreign ecosystem. One prior study conducted in Maine documented population dynamics between Asian shore crabs and native species during natural declines of the Asian shore crab population (Block et al. 2019). However, their results were inconclusive showing no strong correlation between declines in Asian shore crab populations and increases in resident species population levels.

The Marine Education Center in Harbor Island, Mamaroneck is located on a Long Island Sound Estuary and since 2018 has been able to seemingly reduce the invasive Asian shore crab population in a nearby estuary through programs offered to the public in which Asian shore crabs were removed from the estuary. As a result, population levels of resident crab species, such the resident *Cancer irroratus* (Atlantic rock crab) appear to have increased rapidly in this Harbor Island estuary. However, at that time no data was collected at this site to track the effects of the reduction in Asian shore crab levels on population dynamics of the resident species, and thus there was no concrete evidence for this phenomenon occurring.

Therefore, the goal of this study was to document changes in populations of several intertidal resident species as Asian shore crab population levels decreased in an estuarine intertidal zone. The intertidal resident species documented included the *Cancer irroratus* (Atlantic rock crab), *Littorina littorea* (Common periwinkle), and *Modiolus demissus* (Atlantic Ribbed Mussel), among others. A secondary goal was to document the size (mean carapace length) and sex ratios of the Asian shore crab population as its population decreased. We hypothesized that the reduction in Asian shore crab populations in this estuary would coincide with gradual population increases in several of the resident species' populations, and a slight increase in mean carapace size of Asian shore crabs. Thus, this study aimed to bridge the gap in the scientific literature regarding the lack of information detailing how native populations recover from Asian shore crab invasions and explore how Asian shore crab demographics may change during a decrease in its own population.

Materials and Methods

Survey Site

This study was conducted at Mamaroneck Harbor, within three rocky estuarine sites on the Long Island Sound in Mamaroneck, New York. All chosen sites were located around approximately 40°56'26.0"N 73°43'33.7"W and were roughly 220 km (linear distance) from the initial discovery of Asian Shore Crabs in 1988 near Townsend Inlet, NJ. Thus, the site is located near the geographic midpoint of the Asian shore crab's invaded range. The substrate at this site consisted of many rocks of varying sizes atop a beach of sand. This site was isolated from the area around it by large rock walls, and Sample site #1 was separated from Sample sites #2 and #3 for the most part by another large rock wall. Sample sites #2 and #3 were separated by no significant geographical features, but rather a set boundary was determined to allow quadrat sampling to take place within an hour of low tide. Therefore sites #2 and #3 did not undergo a removal period, while Sample site #1 was the focus of the removal period, leaving sites #2 and #3 to be used as potential control groups. The criteria to determine the control group would be which site shared the most species with Sample site #1 prior to removal of the Asian shore crabs, allowing for the most accurate comparison.

Population Sampling Techniques

A mixture of six biased and unbiased surveys were conducted at all sites prior to the removal of any Asian Shore Crabs in order to establish baseline population levels. These preliminary surveys were conducted during the period from 8/2/22 to 9/11/22.

Population levels at Sample Site #1 were calculated following the conclusion of the removal period. To evaluate the population levels of resident species, and the *H. sanguineus* population, we used quadrat sampling techniques. Quadrat sampling was conducted at three different sites which spanned the entirety of one beach. During all surveys 3 transects were used in accordance with systematic sampling techniques on Sample site #1, 6 transects were used at Sample site #2, and 4 transects were used at Sample site #3. During each sampling, transects were positioned along each site in varying amounts roughly proportional to the length of each site in meters divided by 9.14, as each transect was spaced 9.14m across from the prior transect. With Sample site #1 being approximately 27.4m, Sample site #2 being approximately 54.8m and Sample site #3 being approximately 36.5m in length, all had varying widths due to the tide and their structures. The starting position of these transects varied from roughly -3m to +4.5m above mean low water (MLW), varying based upon different tide position at the onset of placement of a transect. The quadrats used were $1.22m^2$ and were placed every 1.524m along transects that were positioned on each site. Rocks and shells within quadrats were overturned by hand and the sand underneath was examined by hand during biased quadrat surveys. After examination, rocks and shells were placed back at their previous positions and orientations. Spacing between individual quadrats along transects was determined using a Milwaukee 30ft wide blade measuring tape for surveys #1-6, and the remainder were conducted using a Milwaukee 25ft standard blade. During all surveys Fiddler Crab population levels would be measured by the locations of Fiddler Crab holes.

Initial raw quadrat data was at first written on paper notebooks in the field and was later converted into Excel. Excel was then used to create graphs in order to interpret the data and calculate values. Excel was also used to calculate the Shannon-Weiner Diversity Index ($H' = -\sum_{i=1}^{s}(\text{pi})(\ln pi)$ where H' is the diversity index, pi = proportion of all species constituted by species "i", S = Number of species in the community), which was used to compare changes in the species diversity at Sample sites #1 and #2, and to calculate changes in the effective number of species (ENS).

Removal and Demographics of *H. sanguineus*

Following the preliminary biased and unbiased quadrat surveys, removal efforts began in order to cause a decrease in the Asian shore crab population. Removal efforts were conducted solely at Sample Site #1 and consisted of a collection of an average of 178 Asian shore crabs per removal at the chosen site. For every 10th crab, a measurement of the carapace took place in order to determine the Asian shore crab mean carapace size over the study period. Measurement was taken to the nearest tenth of a centimeter for carapace size. At Sample Site #1 within the removal period no baseline measurements were taken regarding Asian shore crab sex ratios, these measurements were thus taken at Sample Site #1 during each of the next two removals within the removal period. Thus, conclusions based on sex ratios were obtained with data taken under a smaller time period (10/11/22 - 11/2/22) than other data regarding Asian shore crab demographics (9/28/22 - 11/2/22).

Demographic data was at first written on paper notebooks in the field and was later converted into Excel. The Kruskal-Wallis test was used to calculate p-values regarding changes in carapace size of the Asian shore crab population (Significance threshold: $p < 0.05$).

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Results

Population Dynamics

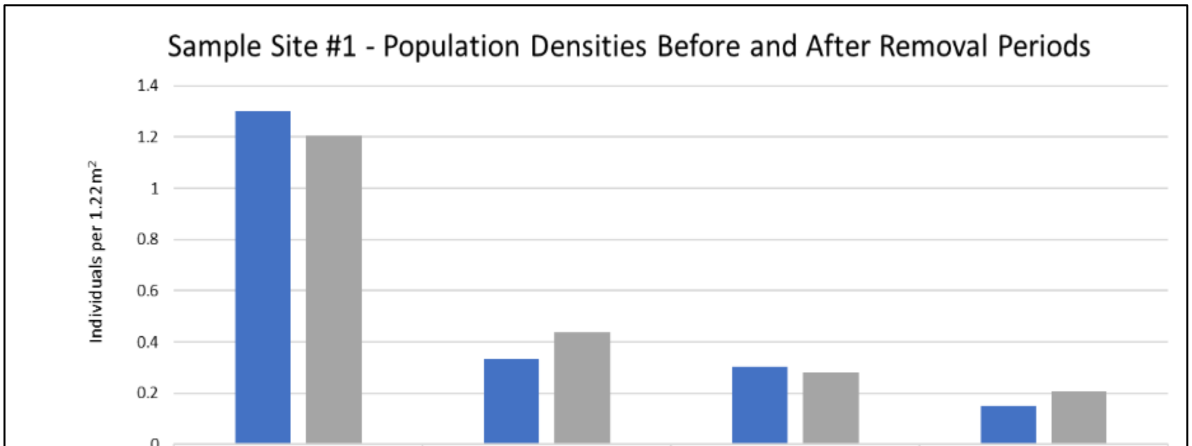
Within the baseline unbiased quadrat surveys the mean Asian shore crab population density was 0.012 individuals/1.22m^2 at Sample site #3, with none found at Sample site #2, and a relatively small 0.012 individuals/1.22m^2 at Sample site #3 (Table 1). Fiddler crabs were only found at Sample site #2 and had a population density of 0.056 individuals/1.22m^2 there. Under baseline unbiased quadrat surveys the Mud snail dominated Sample sites #1 and #3 having the highest population density at each site (0.273 and 0.226 individuals/1.22m^2 at each site, respectively). However, Mud snail population densities were lower at Sample site #2 (0.028 individuals/1.22m^2), where Mussels dominated (0.333 individuals/1.22m^2). Both Periwinkle and Fiddler crab populations would remain relatively similar across all sites (Table 1).

Table 1. Population density of individuals in a given species per 1.22m^2 across all three Sample sites measured in the baseline unbiased quadrat surveys.

Population Density By Species Within Each Sample Site Prior To The Removal Period			
Species		**Individuals per 1.22m^2**	
Asian Shore Crab	1.303	1.569	0.572
Rock Crab	0.333	0.472	0.059
Mussel	0.303	0.319	N/A
Periwinkle	0.152	0.041	0.035
Oyster	0.727	0.389	0.107
Fiddler Crab	N/A	0.042	0.071
	Sample Site #1	**Sample Site #2**	**Sample Site #3**

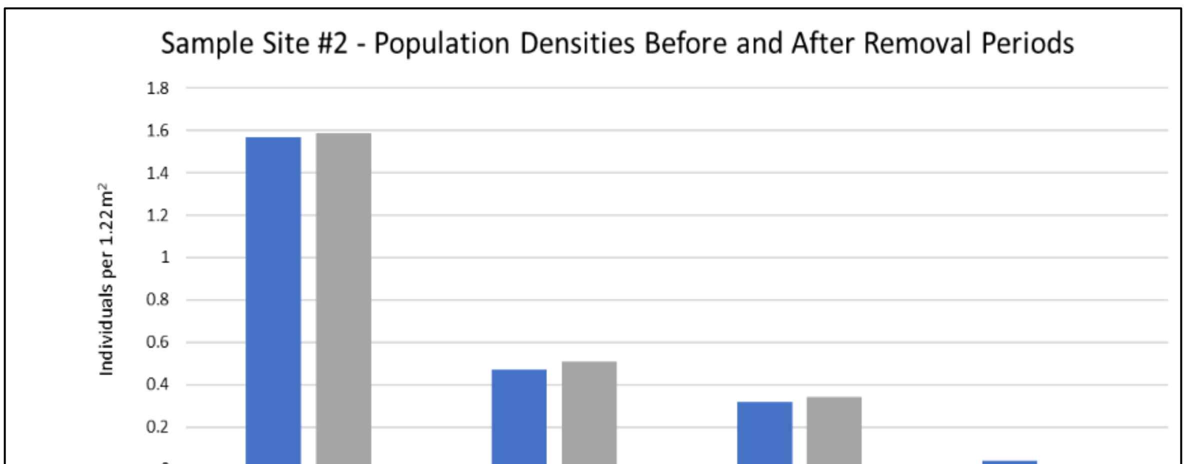
Similarly, to the baseline unbiased surveys, there was a disparity across all three sites in both the number of species and population densities of those species within baseline biased surveys. For example, the Rock crab was calculated to have a population density of 0.333 individuals/1.22m^2 at Sample site #1, 0.472 individuals/1.22m^2 at Sample site #2, and 0.059 individuals/1.22m^2 at Sample site #3.

This would, however, change within Sample Site #1 following the removal periods targeted on that site (Figure 1). Prior to the removal period, within Sample Site #1 the Asian shore crab was calculated to have a population density of 1.303 individuals/1.22m^2, and the Rock crab was calculated to have a population density of 0.333 individuals/1.22m^2. However, following the removal period the Asian shore crab was calculated to have a population density of 1.205 individuals/1.22m^2 and the Rock crab was calculated to have a population density of 0.436 individuals/1.22m^2 in Sample Site #1. Also prior to the removal period Mussels were calculated to have a population density of 0.303 individuals/1.22m^2 and Periwinkles were calculated to have a population density of 0.151 individuals/1.22m^2 in Sample Site #1. And following the removal period Mussels were calculated to have a population density of 0.282 individuals/1.22m^2 and Periwinkles were calculated to have a population density of 0.205 individuals/1.22m^2 in Sample Site #1. This data represents an 8% decrease in the Asian shore crab population density, a 7% decrease in the Mussel population density, a 35% increase in the Periwinkle population density, and a 31% increase in Rock crab population density, within Sample site #1 (Figure 1).



	Asian Shore Crab	Rock Crab	Mussel	Periwinkle
Prior to Removal	1.303	0.333	0.303	0.152
Post Removal	1.205	0.436	0.282	0.205

Figure 1. Population density of individuals in a given species per 1.22m^2 within Sample Site #1 as measured with biased systematic quadrat surveys. Data is separated by differing time periods; Group One (blue) represents population density of a species prior to the removal period, while Group Two (Grey) represents population densities following the removal period. Removal was enacted directly upon Sample Site #1.



	Asian Shore Crab	Rock Crab	Mussel	Periwinkle
Prior to Removal	1.569	0.472	0.319	0.042
Post Removal	1.589	0.507	0.342	0.014

Figure 2. Population density of individuals in a given species per 1.22m^2 within Sample Site #2 as measured with biased systematic quadrat surveys. Data is separated by differing time periods; Group One (blue) represents population density of a species prior to the removal period, while Group Two (Grey) represents population densities following the removal period. Removal was not enacted directly upon Sample Site #2.

Removal was not enacted directly upon Sample Site #2; however, changes would still be calculated to use as a control group (Figure 2). Prior to the time period of the removal period, within Sample site #2 the Asian shore crab was calculated to have a population density of 1.569 individuals/1.22m^2, and the Rock crab was calculated to have a population density of 0.472 individuals/1.22m^2. However, following the time of the removal period the Asian shore crab was calculated to have a population density of 1.589 individuals/1.22m^2 and the

Rock crab was calculated to have a population density of 0.507 individuals/1.22m^2 in Sample Site #2. Periwinkles were calculated to have a population density of 0.042 individuals/1.22m^2 in Sample Site #2 and following the time of the removal period Periwinkles were calculated to have a population density of 0.014 individuals/1.22m^2 in Sample Site #2. Mussels were also calculated to have a population density of 0.319 individuals/1.22m^2 in Sample Site #2 and following the time of removal period Mussels were calculated to have a population density of 0.342 individuals/1.22m^2 in Sample Site #2. This data represents a 1% increase in the Asian shore crab population density, a 67% decrease in the Periwinkle population density, a 7% increase in Mussel population density, and a 7% increase in Rock crab population density, within Sample site #2 (Figure 2).

Table 2. Population density of individuals in a given species per 1.22m^2 across all three Sample sites measured in the baseline biased quadrat surveys.

Population Density By Species Within Each Sample Site Prior To The Removal Period			
Species		**Individuals per 1.22m^2**	
Asian Shore Crab	0.121	N/A	0.012
Mud Snail	0.273	0.028	0.226
Mussel	0.030	0.333	0.012
Periwinkle	0.061	0.014	0.060
Oyster	0.242	0.125	0.107
Fiddler Crab	N/A	0.056	N/A

Population levels as measured by biased quadrat surveys would be used to calculate the Shannon-Weiner diversity index in Excel. From this we calculated the Effective number of species (ENS) as another measure of diversity.

Prior to removal at Sample site #1 there was a calculated Shannon diversity index of 1.057, with an ENS of 2.879. And following the removal period at Sample Site #1 there was a calculated Shannon diversity index of 1.140, with an ENS of 3.127. However, prior to removal period there was a calculated Shannon diversity index of 1.234, with an ENS of 3.433 at Sample site #2. Following the removal period there was a calculated Shannon diversity index of 1.226, with an ENS of 3.409 at Sample Site #2. This data represents a 0.247 increase in the ENS at Sample site #1, and a 0.024 decrease in the ENS at Sample site #2 following the removal period (Figure 3).

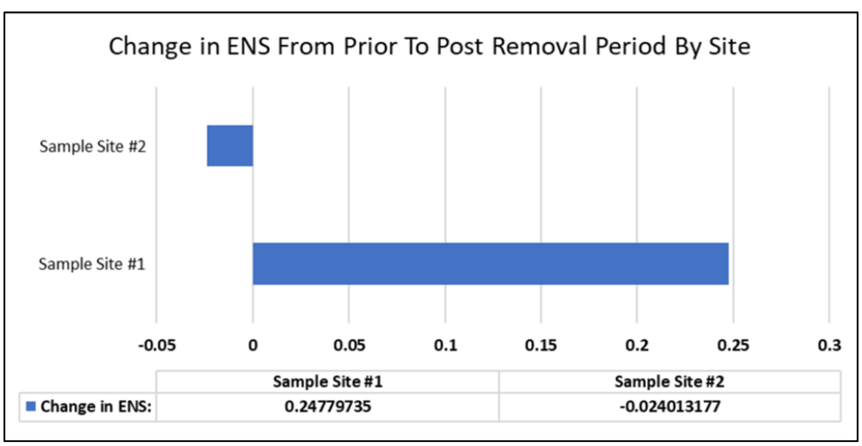


Figure 3. The change following the period of removal in the Effective Number of Species (ENS) for Sample sites #1 and #2.

Asian Shore Crab Demography

Mean Asian shore crab carapace lengths following baseline quadrat surveys and in the first measurement of the removal period were calculated to be 1.05cm, with a wide range of 1.6cm with a minimum length of 0.4cm and a maximum of 2cm. This maximum of 2cm would continue to be the maximum across all measurements within the first period of removal. However, by the end of the removal period the mean Asian shore crab carapace lengths would increase to 1.35cm. Thus, during the removal period Asian shore crab size would very slightly increase, while retaining an identical maximum size, slightly larger minimum size, and a similar variability (Figure 4). The Kruskal-Wallis test was calculated and used to determine that the changes in carapace size were not statistically significant (p = .181).

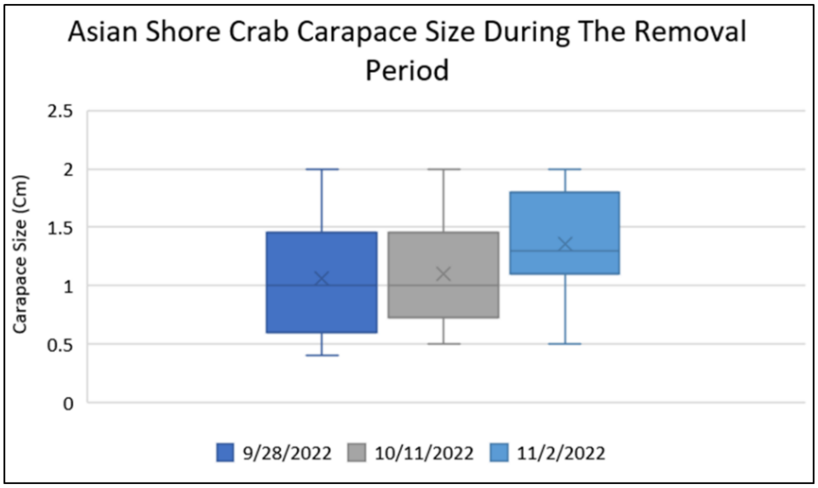


Figure 4. Displays distribution of carapace sizes in cm of *Hemigrapsus sanguineus* (Asian shore crab) as measured on three different dates during the first removal period. Changes in carapace size were not statistically significant (p = .181).

Discussion

Population Dynamics

As expected, with initial baseline biased quadrat surveys, significantly more mobile organisms were represented in our data compared to our baseline unbiased quadrat surveys, with two new species being represented (Rock crab and Periwinkle). Typical limitations were experienced within biased quadrat surveys as only mobile organisms visually noticed and identified by those conducting the survey could be counted within quadrat data. Still, biased quadrat surveys were used to model population density over time as they could account for a greater portion of mobile species which may take cover under obstacles in the intertidal zone, such as Asian shore crabs and Rock crabs, which were underrepresented in the unbiased surveys. Traditional limitations must still be considered within the biased quadrat sampling methods as this method leads to an overestimation of slow-moving species. Possibly leading to Rock crab population levels being inflated comparative to the relatively faster Asian shore crab population.

Within measurements taken by the initial baseline biased quadrat surveys, Asian shore crabs dominated the environment, being the most densely populated species throughout all three Sample sites (Table 1). There was also a stark contrast between population densities of native species such as the Rock crab (0.264

individuals/1.22m^2) and the invasive Asian shore crab (1.079 individuals/1.22m^2), demonstrating the dominance of the Asian shore crab over this invaded ecosystem.

As the removal period was only enacted upon Sample Site #1, this site would act as our experimental group. While data from Sample Site #2 would be used as a control group to determine the true effects of these changes as no removal period had been enacted upon it. And there would be a minor change (8% decrease) in Asian shore crab levels within Sample site #1 as a result of the removal period, comparative to a more minor change (1% increase) in Sample site 2. Ultimately, Sample site #3 was excluded from comparison as it shared the least number of species with Sample site #1. Therefore, Sample Sites #1 and #2 were chosen to evaluate changes as they had the most similar makeup of species and thus could be used to compare changes in the greatest number of species. These shared species would be used to compare differences in population changes between sites over time.

The drastic (67%) decrease in Periwinkle population found in Sample site #2 was not considered due to the extremely low sample of Periwinkles found (Before removal, n=3. After removal n=1). Likewise, due to low sample sizes within Sample site #1 (Before removal, n=5. After removal n=8) we did not draw any conclusions based on Periwinkle population changes there. Although a longer-term study may be able to remedy the issue of a low sample size. The relatively drastic increase in Rock crab population density in Sample site #1 (31% increase) as opposed to the relatively minor increase found at Sample site #2 (7% increase) suggests that the removal methods focused on Sample site #1 may have had an overall positive effect on the Rock crab population (Figure 1 and Figure 2). Although increases in the Rock crab population may have been at least partially accounted for by unknown confounding variables, as there was an increase in Rock crab populations at all sites measured, regardless of a removal being enacted upon that site. A study over a longer period is also needed to determine whether these impacts are merely short-term changes or are more permanent shifts in the population dynamics of this ecosystem. And a longer period of removal could perhaps be used to cause even further reductions in Asian shore crab population levels, perhaps leading to further increases in native populations such as the Rock crab population.

The difference in change of ENS at Sample site #1 (increase of 0.248 ENS), and the change of ENS at Sample site #2 (decrease of 0.024 ENS), demonstrates that the reduction in Asian shore crab population experienced at Sample site #1 allowed for increased species diversity (Figure 3).

Conclusions Regarding Carapace Sizes and Sex Ratios

Under the initial baseline Asian shore crab measurements at Sample site #1 within the first removal period there was a mean carapace length of 1.05cm. Throughout the course of the removal period there was a slight increase in mean carapace size, changing to 1.10cm in the second removal period, and 1.35cm in the final removal period ($p = .181$). Variability remained nearly the same and the maximum size would stay exactly the same (Figure 4). The removal period was determined to not have a statistically significant effect on carapace size ($p = .181$). Sex ratios would also stay roughly the same, changing from 1.2 males to females to 1.32 males to females. Larger Asian shore crabs may have been over accounted for within this data as smaller crabs could hide in the substrate of the site, making them harder to catch and measure. A study with a greater number of samples measured across a longer period of removal may be able to determine with certainty the effects of a reduction in Asian shore crab population on Asian shore crab demography.

Acknowledgments

I would like to thank Kyle Troy for acting as my mentor during this project. Kyle taught me many necessary components of this project (population sampling methods, data analysis, etc.) and field work needed for this research was completed under her supervision.

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