Population Structure and Dynamics of *Hemigrapsus sanguineus* Between 2008 and 2020

by

Dakota Crowley

Submitted to the Department of Environmental Studies

School of Natural and Social Sciences

in partial fulfillment of the requirements

for the degree of Bachelor of Arts

Purchase College

State University of New York

January 2021

Sponsor: Dr. George Kraemer

Second Reader: Dr. Allyson Jackson

Abstract

An invasive species is one that is introduced into a new ecosystem. Through researching invasive species, we may begin to understand their impact on their introduced. *Hemigrapsus sanguineus*, known as the Asian Shore Crab, is an invasive crab species from the western Pacific region now found on the eastern seaboard of the United States. During low tide in September 2020, *Hemigrapsus sanguineus* were collected from the Read Wildlife Sanctuary site in Rye, New York. Samples were randomly collected by hand for thirty minutes per intertidal zone by removing them from below rocks. It was determined that there is a significant difference in carapace width between at least two of the three intertidal locations in 2020 and 2008, and that these population groups are not the same as 2020 appears larger (may be biased). Crabs closest to the water appear to have the highest egg mass, and intertidal location is inversely proportional to the average female egg mass. Egg mass between elevation groups has shown to be different. The 2020 data shows an increase in size of gravid crabs, which may be biased. The 2020 data contradicts previous research arguing that average density was higher in the high tidal zone than in the low tidal zone (Huston), and that gravid females are less likely to be found in the high intertidal zone (Hobbs et. al). The hypotheses that the species is seeing a decrease in size, and that the frequency of gravid females in the smallest reproductively mature classes would continue to increase were not supported. More research must be done to determine the differences and change in population density, as there was no difference in egg mass between elevation groups.

Introduction

An invasive species is one that is foreign and introduced into a new ecosystem either intentionally or accidentally. Researching invasive species is vital to understanding their impact on the environment they have been introduced to. In general, invasive species tend to have negative impacts on their environments, both ecologically and economically; however, as each invasive species is unique, so are the interactions between the species and the introduced environment. From an ecological standpoint, it is important to consider the interactions between the invader species and the native community. As for economics, there is the consideration of reduction of the native fishing sector, and the cost of restoration for damages and rehabilitation of the ecosystem.

The success of invasive species has been attributed to many common mechanisms. For example, invasive species often lack predators, parasites, or competitors which allows the species to thrive (Epifanio, 2013). Often, these invasive species are capable of producing a high quantity of widely dispersing offspring, which allows the species to populate and spread quickly; however, population sizes of invasive species are often characterized by "boom-bust" dynamics, where the species experiences a rapid increase followed by a decline often in response to self-limitation via resource depletion (Griffen, 2020). For these reasons, it is vital to analyze the population structure and dynamics of invasive species. Population structure and dynamics may be defined as the size, distribution, and reproduction of a species and how this may change over time (Sbordoni et. Al, 2013).

Hemigrapsus sanguineus, also known as the Asian Shore Crab, is an invasive crab species from the western Pacific region, possibly Japan, that was introduced to northeastern coast of America in the 1980s, most likely from the transport of ballast water (O'Connor, 2018). The species has spread around the eastern seaboard and can be found in the Long Island Sound, where they have become abundant (Kraemer, 2019).

The purpose of this study is to collect data that may be added to a long-term data set that has examined *Hemigrapsus sanguineus* over generations. The objectives are to measure population changes in density over time, determine whether the species exhibits a decrease in size , and to determine changes in reproduction (Kraemer, 2019). It is hypothesized that the species will exhibit a decrease in carapace width consistent with the findings of Kraemer (2019 in which the proportion of the crabs larger than 24 mm in carapace width reduced from 10.1% of the population in 2005 to 1.4% in 2017. It is also predicted that there will be a decrease in population density consistent with the theory of "boom-bust" dynamics and the findings that Asian Shore Crab density has declined by nearly 90% since 2012 (Bloch, 2019). It is hypothesized that there will be a large frequency of smaller gravid females (12-14mm in carapace width), which will continue to reduce population reproductive output as was shown in Kraemer (2019).

Materials and Methods

The study site is located at Read Wildlife Sanctuary (Rye, NY; 40°57'58.85"N, 73°40'7.07"W), a part of Manursing Island in the Long Island Sound. The site is defined by its gradual slope and rocky intertidal region consisting of stones of various sizes upon a sand/gravel-mud substrate. Since native populations have been monitored along with invasive species, it has been concluded that the intertidal abundance of the *Hemigrapsus sanguineus* is highest from June to September (Kraemer et al. 2007) making this time of year crucial for determining population structure and dynamics of *Hemigrapsus sanguineus.*

During low tide in September 2020, *Hemigrapsus sanguineus* were collected from the Read Wildlife Sanctuary site. Samples were collected at three different intertidal zones: the high intertidal zone (28 to 40 meters), the middle intertidal zone (14 to 26 meters) and the low intertidal zone (0 to 12 meters). Samples were randomly collected by hand for thirty minutes per intertidal zone by removing them from below rocks. During this sampling, crabs of all sizes were collected from beneath rocks of varying sizes. The samples were then transferred into bags of ten crabs and labelled with the date and intertidal zone, which were then frozen for analysis.

The population samples of *Hemigrapsus sanguineus* were removed from the freezer, and their intertidal zone, sex, carapace width and reproductive status were catalogued and recorded. Sex of small individuals was recorded using a dissecting microscope (120x) which could identify male gonopods. A caliper was then used to determine the width of their carapace. Female samples were further investigated for the presence of eggs to determine their reproductive status. Gravid female samples had their mass of eggs removed, which were then dried overnight at 60 °C and weighed to obtain their egg mass. The 2020 data was compared to 2008 data collected by Dr. George Kraemer and analyzed using ANOVAs and T-tests computed in Microsoft Excel.

Results

<u>Figure 1:</u>

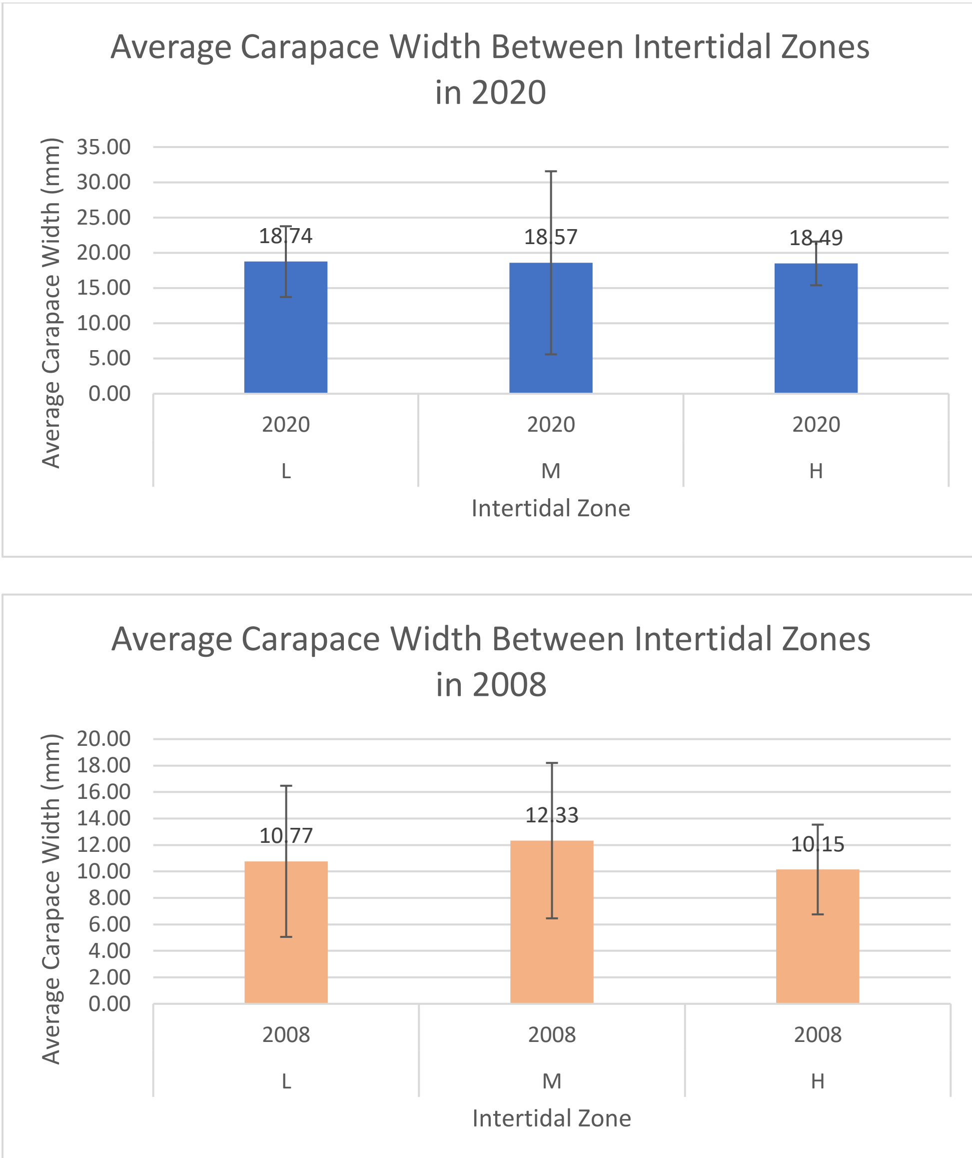


Figure 1. Average carapace width in low (L), middle (M), and high (H) intertidal zones in 2020 compared to 2008.

The average carapace width for the lowest intertidal zone was determined to be 18.74mm. The average carapace width for the middle intertidal zone was 18.57mm. The average carapace width for the high intertidal zone was determined to be 18.49mm (Figure 1). A single-way ANOVA determined the averages differed significantly (3.26 P-value = 0.039).

In 2008, the average carapace width for the lowest intertidal zone was 10.77mm. The average carapace width for the middle intertidal zone was 12.33mm. The average carapace width for the highest intertidal zone was 10.15mm (Figure 1).

Figure 2:

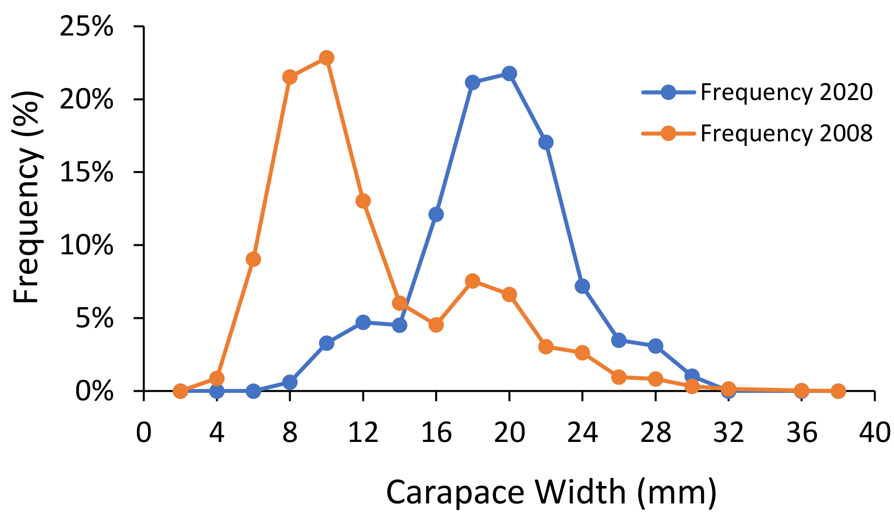


Figure 2. The combined frequency and carapace size for crabs caught in 2008 and 2020.

In 2008, the frequency of crabs peaked at nearly 22.84% being around 10mm in carapace width, with a secondary peak at 7.54% at 18mm in carapace width. In 2020, the frequency of crabs peaked at 21.77% at 20mm in carapace width (Figure 2). The two collections were compared using a t-test (t = 26.75, P(T<=t) = $3.3*10^{-140}$). These two data sets do not meet the assumptions of normality.

Figure 3:

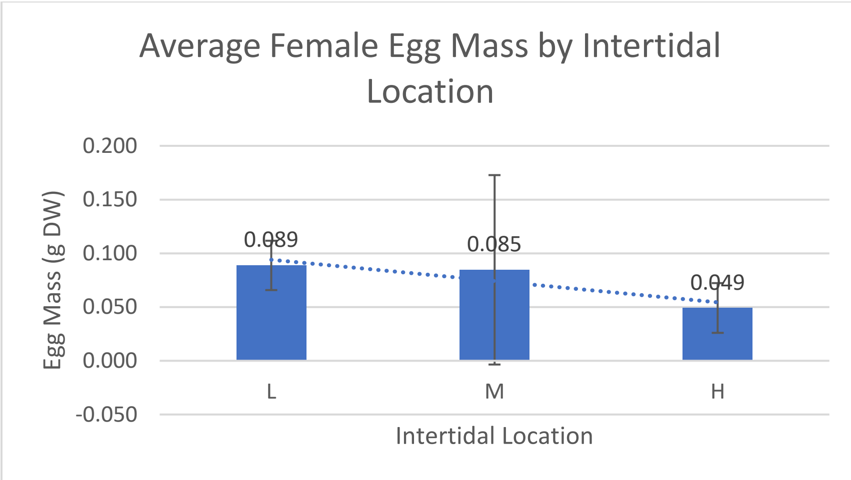


Figure 3. Average female egg mass by low (L), middle (M), and high (H) intertidal locations.

In the highest intertidal zone, the average female egg mass for crabs caught in 2020 is 0.049 grams in dry weight. In the middle intertidal zone, the average female egg mass for crabs caught in 2020 is 0.085 grams in dry weight. In the lowest intertidal zone, the average female egg mass for crabs caught in 2020 is 0.089 grams in dry weight (Figure 1). The overall average female egg mass was determined to be 0.071 grams in dry weight. After running a one-factor ANOVA, it was determined the F value was 2.33, the F Crit. value was 3.16, and the P-value was 0.11.

<u>Figure 4:</u>

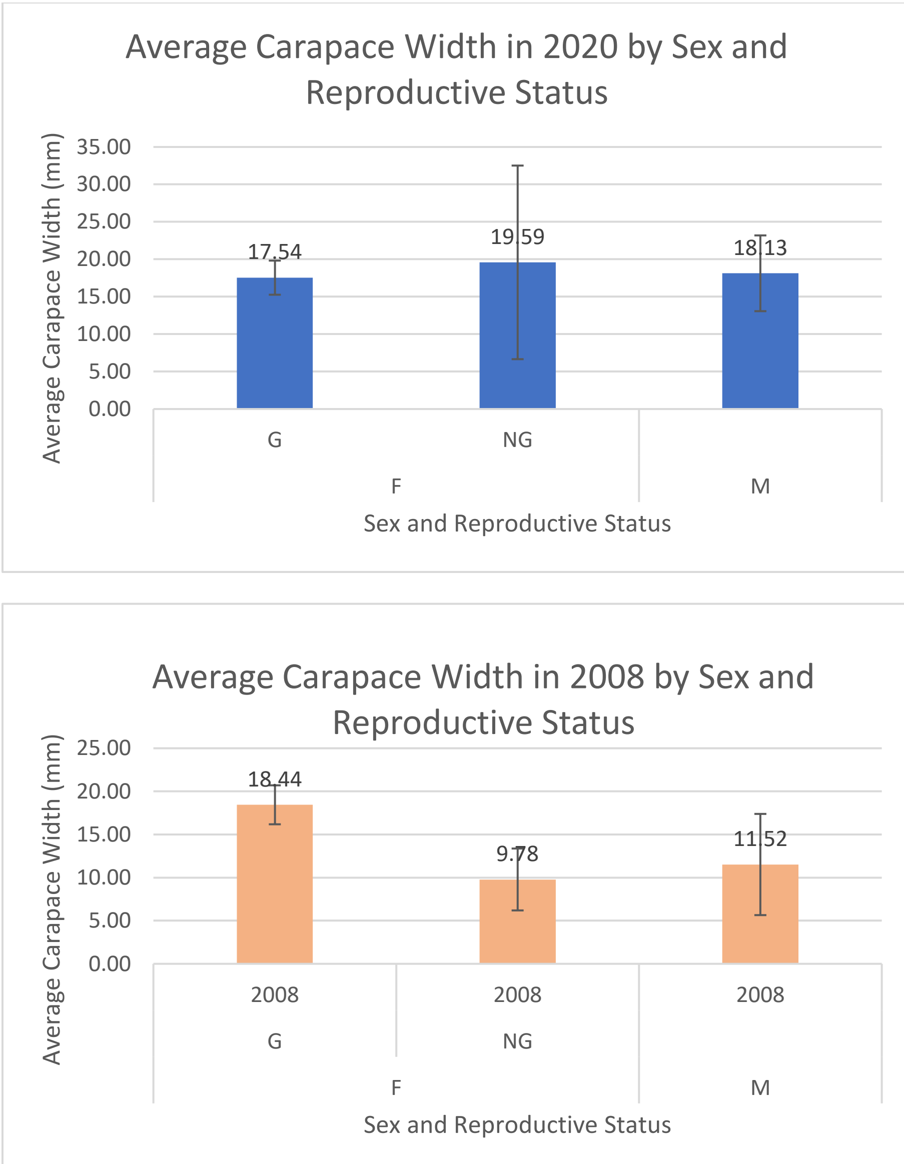
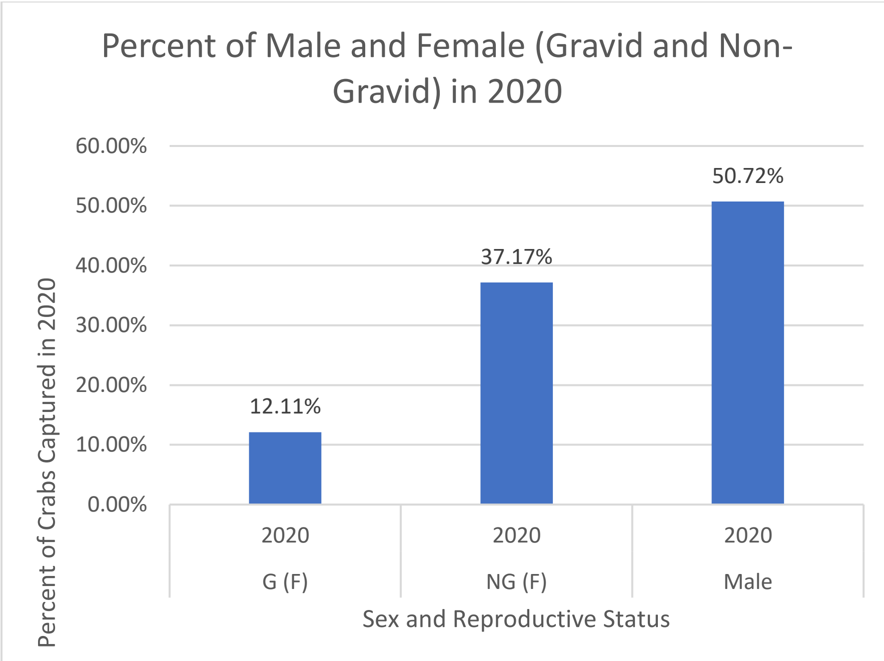


Figure 4. Average carapace width of gravid females, non-gravid females, and males in 2020 compared to 2008

In 2020, the average carapace width of gravid females was 17.54mm. The average carapace width for non-gravid females was 19.59mm, higher than that of the gravid females. The average carapace width for males was 18.13mm, larger than the average width of gravid females but smaller than the width of the non-gravid females (Figure 4).

In 2008, the average carapace width of gravid females was 18.44mm. The average carapace width for non-gravid females was 9.78mm, lower than the average width of gravid females. The average carapace width of males was 11.52mm, larger than the non-gravid females but smaller than that of the non-gravid females (Figure 4).

<u>Figure 5:</u>



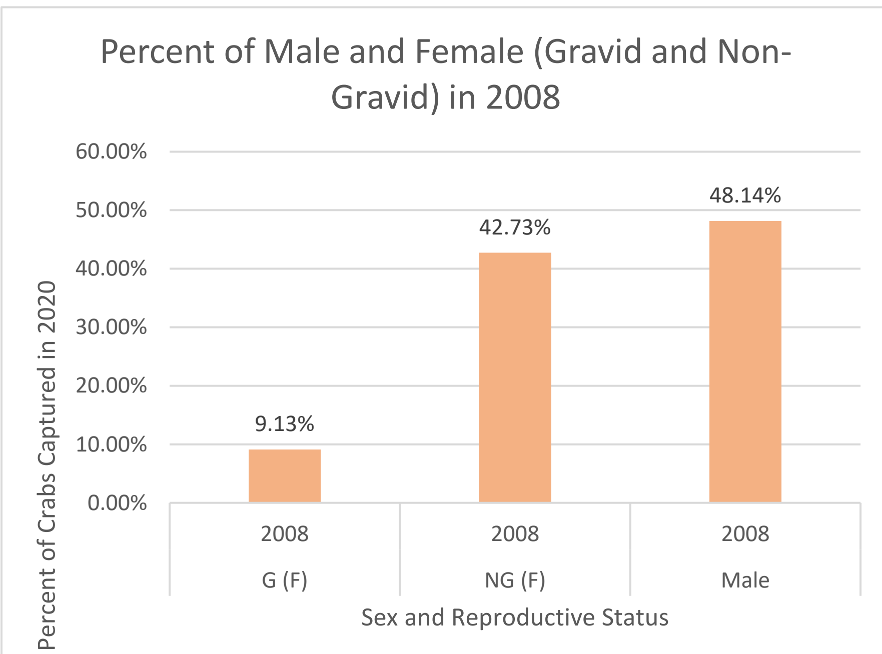


Figure 1 depicts the percent of gravid females, non-gravid females, and males in the year 2020 compared to 2008.

Of the total 487 crabs collected in 2020, 12.11% were gravid females, and 37.17% were non-gravid females making 49.28% of the crabs collected female and 50.72% male (Figure 5).

In 2008, 9.13% of the total crabs collected were gravid females, and 42.73% were non-gravid females making 51.86% female and 41.14% male.

Figure 6:

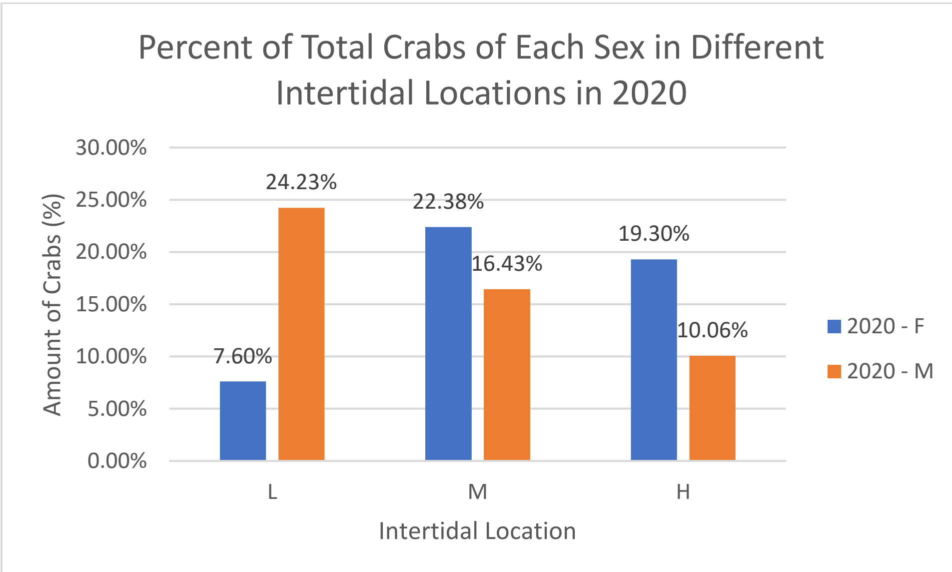
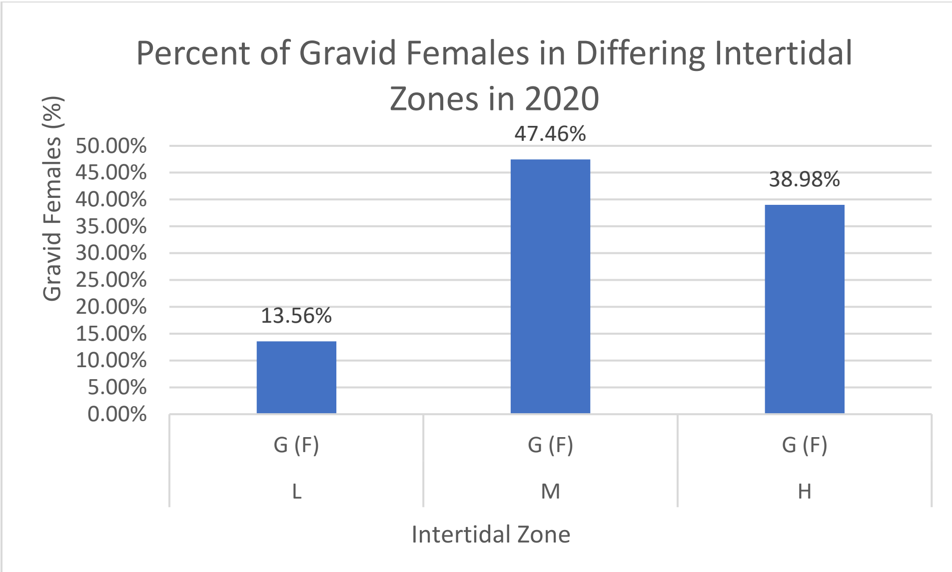


Figure 6. Percent of female and male crabs in low (L), middle (M), and high (H) intertidal zones in the 2020 collection.

The lowest intertidal zone contained 31.83% of the 2020 collection and was composed of 7.60% females and 24.23% males for a ratio of 37:118. The middle intertidal zone contained 38.81% of the 2020 collection and was composed of 22.38% females and 16.43% males for a ratio of 109:80. The highest intertidal zone contained 29.36% of the 2020 collection and was composed of 19.30% females and 10.06% males for a ratio of 94:49 (Fig. 6).

Figure 7:



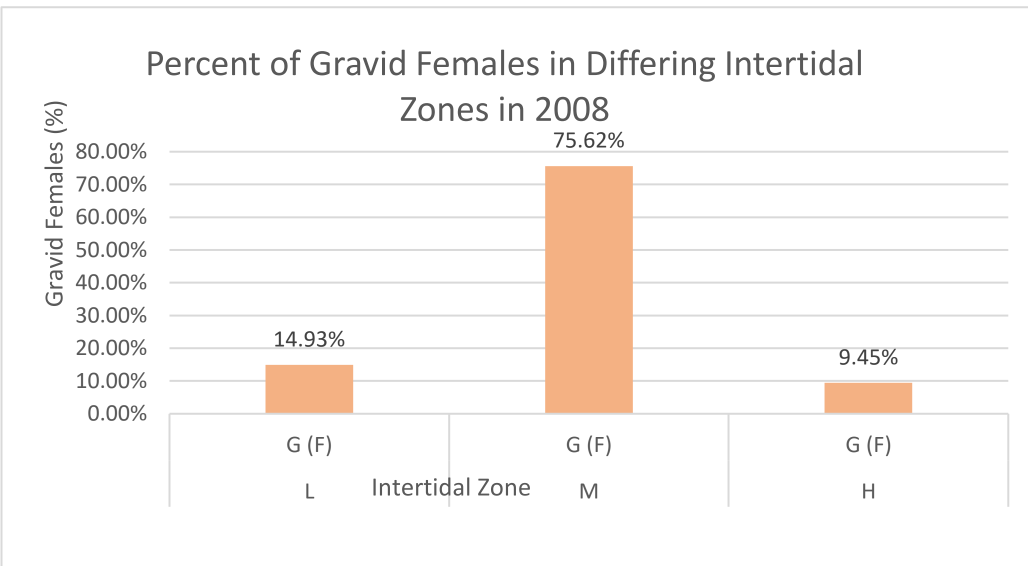


Figure 7. The percent of gravid female crabs by low (L), middle (M), and high (H) intertidal zones in 2020 compared to 2008.

In the 2020 collection, the lowest intertidal zone contained 13.56% of the total gravid females, the middle intertidal zone contained 47.46% of the total gravid females, and the highest intertidal zone contained 38.98% of the total gravid females (Figure 7).

In the 2008 collection, the lowest intertidal zone contained 14.93% of the total gravid females, the middle intertidal zone contained 75.62% of the total gravid females, and the highest intertidal zone contained 9.45% of the total gravid females (Figure 7).

Figure 8:

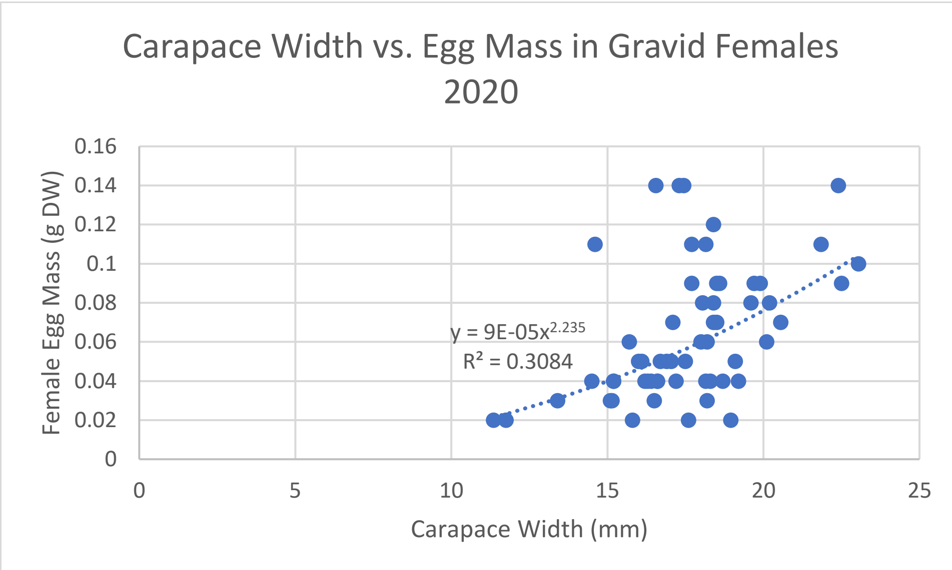


Figure 8. The average carapace width in comparison to dry weight egg mass for gravid crabs collected in 2020.

The lowest average egg mass (g DW) was determined to be 0.02g, and the highest average egg mass was determined to be 0.49g. The smallest average carapace width for a gravid female was 15.7mm, and the largest average carapace width for a gravid female was 18.88mm. Most gravid females have an egg mass of 0.02g to 0.14g (Fig. 8).

Figure 9:

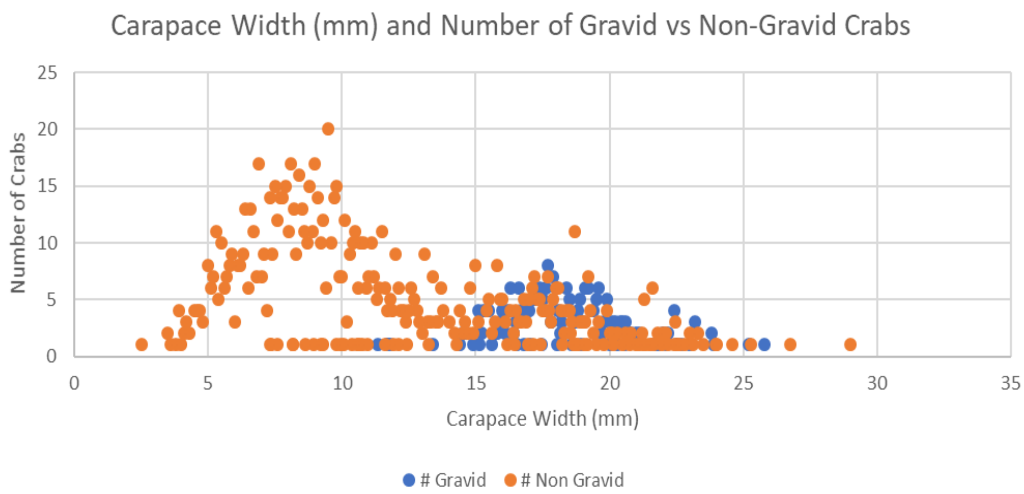


Figure 9. The carapace width of gravid female (blue) and non-gravid female (orange) crabs.

There are more non-gravid females than gravid females. The most non-gravid females peak before reaching a carapace width of 15mm, where the number of gravid females begin to cluster and peak between 15 and 20mm. The first gravid females are seen at a carapace width of 11.35mm (Figure 9).

Discussion

We can reject the null hypothesis that there is no significant size difference in carapace width between elevation groups in 2020 because F is larger than F-crit, and because the P-value is less than the alpha of .05. Therefore, there is a significant difference in carapace width between at least two of the three intertidal locations in 2020 (low, middle, and high).

A single-factor ANOVA was also conducted for carapace width and intertidal location of 2008 crabs (F 40.30, P-value 0, F-Crit. f 3.00). We can reject the null hypothesis that there is no significant size difference in carapace width between elevation groups in 2008 because F is larger than F-crit, because the P-value is less than the alpha of .05. Therefore, there is a significant difference in carapace width between at least two of the three intertidal locations in 2008 (low, middle, and high).

The P-values in the one-tailed test and the two-tailed test are both smaller than the alpha of 0.05, meaning we can reject the null hypothesis that the population groups are the same. This is noticeable as in 2008, the frequency of crabs peaked at nearly 22.84% being around 10mm in carapace width and in 2020, the frequency of crabs peaked at 21.77% at 20mm in carapace width (figure 2). In all three intertidal zones, the 2020 average carapace width appears larger than the 2008 average width and collective average width. This data argues that carapace width has increased since 2008, which is inconsistent with previous findings which show decreases in the density of larger crabs and a reduction in average and maximum sizes of both males and females (Kraemer, 2019). This may be due to unintentional bias against small crabs which is elaborated on in the discussion. These findings do not support the hypothesis that the crab population may be decreasing in carapace width.

The data in figure 3 shows the crabs closest to the water appear to have the highest egg mass in grams of dry weight on average, and that the intertidal location is inversely proportional to the average female egg mass. Both the lower and middle intertidal zones are above the average egg mass of the collective intertidal zones, in comparison to the high intertidal zone which falls far below the collective average; however, after running a one-factor ANOVA we cannot reject the null hypothesis that the egg mass between elevation groups is the same. The data in figures 8 and 9 suggest sexual maturity in females may begin as early as reaching 11.35mm in carapace width, yet most may reach sexual maturity by the time they reach around 15mm, as that is where the gravid clusters begin to form (Figure 9). In addition, almost all the crabs prior to 15mm are non-gravid females. It also shows that if sexual maturity begins at around 15mm, there are still non-gravid crabs of this width or larger. It was hypothesized the frequency of gravid females in the smallest reproductively mature classes (12–14 mm in carapace width) would continue to increase, as seen in Kraemer, 2019; however, the 2020 data suggests an increase in larger mature classes. This may be due to the possible unintentional bias towards the collection of larger crabs which is elaborated on in the discussion. Figure 8 also suggests as the carapace width increases, the potential for holding a larger egg mass increases. Egg mass follows a power relationship, but has a low R^2 value leaving a lot of variance unexplained. There is also an outlier of 16.3mm carapace width and 0.49g mass (Figure 8).

Of the total 487 crabs collected in 2020, 12.11% were gravid females, and 37.17% were non-gravid females making 49.28% of the crabs collected female and 50.72% male (Figure 5). The lowest intertidal zone contains the highest percentage of male crabs, followed by the middle, then highest intertidal zone (Figure 6). The middle intertidal zone contained the highest percentage of female crabs, followed by the highest intertidal zone, then the lowest (Figure 6). This is consistent with the findings that gravid females were found in the highest percentage in the middle intertidal zone, then the highest intertidal zone, and then the lowest (Figure 7). These findings suggest that male crabs may prefer a lower intertidal zone whereas female crabs, especially when carrying eggs, may prefer a higher intertidal zone. Further research would need to be performed to make a definite conclusion. Previous research argues that average density was higher in the high tidal zone than in the low tidal zone (Huston); however, the 2020 findings do not support this as 31.83% of crabs were found in the lower intertidal zone, 38.81% were found in the middle intertidal zone, and 29.36 were found in the high intertidal zone. There is the possibility this difference may be explained by the different sampled locations in the United States and the retrospective definitions of the intertidal zones in meters.

In 2020, the average carapace width of gravid females was 17.54mm, the average carapace width for non-gravid females was 19.59mm, and the average carapace width for males was 18.13mm (Figure 4); however, if you combine 2020 gravid and non-gravid females, the average carapace width for females is 18.5mm, which is extremely close to the male average of 18.13mm (Figure 4). Therefore, it cannot be definitely concluded if there is a notable difference in width between male and female crabs.

Previous literature suggests that gravid females are less likely to be found in the high intertidal zone (Hobbs et. al). This is supported by 2008 data, in which the highest intertidal zone contained only 9.45% of the gravid females. The 2020 data differed in that the lowest intertidal zone contained the least gravid females (13.56% of the total gravid females). Like previous 2008 data, in 2020 the middle intertidal zone contained the largest percent (47.46%) of the total gravid females. The high intertidal zone which Kraemer et. Al and Hobbs et. Al showed typically has the least gravid females was found to have an intermediate percentage of 38.98% in 2020, only 8.48% lower than the middle intertidal zone.

One limitation to the research was the difficulty in comparing 2008 data to 2020 data. The 2008 data set had a significantly larger sample size than the 2020 data, and was collected earlier in the season than the 2020 data. This may partially explain why the populations were so statistically different. For example, the larger carapace size of the 2020 sample in comparison to the 2008 sample may be due to the additional variable that they were sampled later in the season. Another limitation was the use of Microsoft Excel for computing statistics. Because the sample sizes were so different, a two-way ANOVA comparing sex and carapace size for 2020 and 2008 samples could not be computed as Excel does not run unbalanced two-way ANOVAs. In addition, using Excel made it difficult to extrapolate data from the one-way ANOVAs as it did not provide a way to run post hoc tests. A source of error may have been the accidental selection of larger crabs. Although crabs were sampled at random of all sizes and under all types of rocks, it is possible that a larger quantity of larger crabs were selected because they move slower than smaller crabs and are easier to spot and pick up. This may explain some of the unexpected results, such as the higher percent of gravid crabs in the higher intertidal zone (2020) and why it appears that the carapace width has increased since 2020. In addition, although we can make assumptions from comparing the two years of 2020 and 2008 data, it must be noted that in order to determine whether the species exhibits a decrease in size more than two years must be compared or compiled to reach reliable results.

For future experiments and follow-ups, it would be beneficial to sample in the same quantity as prior samples and during the same time period to eliminate some variability. In addition, more care must be taken to ensure the sample collected is random and reflective of the population rather than possibly biased. A more detailed procedure for collection, as well as using a specialized trap or net may be useful in future experiments. It is also important to find a more efficient method of running statistics than through Microsoft Excel. With a different statistics program, post hoc tests such as a Tukey's test could be used to find where the significant difference lies between intertidal locations for carapace width in both the single-factor ANOVAs for 2008 and 2020.

Conclusion

Researching invasive species such as ***Hemigrapsus sanguineus***, the Asian Shore Crab, opens the doors to further understanding the environmental impact a species with lack of predators, parasites, or competitors may have on their introduced environment. This is extremely important, as introduced invasive species tend to have negative impacts on their introduced environments.

The purpose of this study is to collect data that may be added to a long-term data set that has examined *Hemigrapsus sanguineus* over generations. The objectives are to measure population changes in density over time, determine whether the species exhibits a decrease in size, and to determine changes in reproduction (Kraemer, 2019). It is hypothesized that the species will exhibit a decrease in carapace width, a decrease in population density, and contain a continued large frequency of smaller gravid females (12-14mm in carapace width).

It was determined that there was a statistical difference in the populations of the 2008 collection and the 2020 collection, as the 2020 collection appeared to have larger carapace widths in higher frequencies, which does not support previous findings or the hypothesis that the species is seeing a reduction in average and maximum sizes of both males and females (Kraemer, 2019). Although there was a change in population density, more research must be done to determine these differences in order to support the hypothesis especially as there was no difference in egg mass between elevation groups. The 2020 data suggests an increase in larger mature classes, which does not support the hypothesis that the frequency of gravid females in the smallest reproductively mature classes (12–14 mm in carapace width) would continue to increase (Kraemer, 2019).

Literature Cited

Bloch, Christopher P., Curry, Kevin D., Fisher-Reid, Caitlin M., Surasinghe, Thilina D. 2019, November. "Population Decline of the Invasive Asian Shore Crab (*Hemigrapsus sanguineus*) and Dynamics of Associated Intertidal Invertebrates on Cape Cod, Massachusetts," Northeastern Naturalist, 26(4), 772-784. https://doi.org/10.1656/045.026.0408

Epifanio, C. E. 2013, March. Invasion biology of the Asian shore crab *Hemigrapsus sanguineus*: A review. Journal of Experimental Marine Biology and Ecology, 441, 33-49. doi:https://doi.org/10.1016/j.jembe.2013.01.010

Griffen, B.D., Bailey, J., Carver, J. et al. 2020. “Mechanisms of possible self-limitation in the invasive Asian shore crab *Hemigrapsus sanguineus*.” Sci Rep, 10, 16908. https://doi.org/10.1038/s41598-020-74053-5

Hobbs, Niels-Viggo S., J. Stanley Cobb, and Carol S. Thornber. 2017. “Injury, Reproductive Status, and Distribution of *Hemigrapsus sanguineus* (De Haan, 1835) (Brachyura: Varunidae) on the Rocky Intertidal Shores of Rhode Island, USA.” Journal of Crustacean Biology 37 (1): 16–20. https://doi.org/10.1093/jcbiol/ruw002.

Huston, Valerie; Martel, Teresa; and Mohamed, Zimzim, "Density of Hemigrapsus sanguineus and Carcinus maenas in Kettle Cove, Cape Elizabeth, Maine" (2019). Thinking Matters Symposium Archive. 171. https://digitalcommons.usm.maine.edu/thinking_matters/171

Kraemer, George P. 2019. “Changes in Population Demography and Reproductive Output of the Invasive *Hemigrapsus Sanguineus* (Asian Shore Crab) in the Long Island Sound from 2005 to 2017.” Northeastern Naturalist 26 (1): 81–94. https://doi.org/10.1656/045.026.0101.

Lord, Joshua, and Larissa Williams. 2017. “Increase in Density of Genetically Diverse Invasive Asian Shore Crab (*Hemigrapsus Sanguineus*) Populations in the Gulf of Maine.” Biological Invasions 19 (4): 1153–68. https://doi.org/10.1007/s10530-016-1304-1.

O’Connor, Nancy J. 2018. “Changes in Population Sizes of *Hemigrapsus Sanguineus* (Asian Shore Crab) and Resident Crab Species in Southeastern New England (2010-2016).” Northeastern Naturalist 25 (2): 197–201. https://doi.org/10.1656/045.025.0202.

Sbordoni, V., Allegrucci, G., & Cesaroni, D. (2012). Population Structure. In V. Sbordoni, G. Allegrucci, & D. Cesaroni, Encyclopedia of Caves (pp. 608-618). Roma: Academic Press. doi:https://doi.org/10.1016/B978-0-12-383832-2.00090-6