INTRASPECIFIC COMPETITION OF *PAGURUS SAMUELIS* ON SHELL SELECTION AND RECOGNITION

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Abstract

Marine hermit crabs use gastropod shells to protect their soft abdomens. By knowing a hermit crab's shell preference, the dynamics of hermit crab interactions within a species can be better understood for shell selection and exchanges. This research conducted three treatments on the *Pagurus samuelis* hermit crab to test shell recognition ability and selection. The purpose of this experiment was to test intraspecific competition of *P. samuelis* on shell selection and recognition. The gastropod shells originally inhabited by the hermit crabs were all *C. funebralis*. *P. samuelis* females and males were presented with a choice of their original shell and another similar gastropod shell previously inhabited by a *P. samuelis* of the same sex. Overall, when tested individually, females preferred their own shell while males had no preference. However, when *P. samuelis* was presented the same shell choice in the presence of another hermit crab of the same sex, its preference changed. The location of the shell also mattered for the hermit crab's shell choice. The experiments indicate that shell preference is dependent on the presence or absence of a conspecific of the same sex. Also, it was found that a *P. samuelis* hermit crab's sex does make a difference in shell choice selection and preference.

Key words: Crustacean; Hermit crabs; *Pagurus*; Gastropod; Snails; *Chlorostoma*; Intraspecific competition; Shell selection; Shell recognition; Shell influences; Gender differences.

Introduction

ONE major goal in the field of ecology is to understand species interactions. These interactions can be observed with isolated individuals or with combinations of individuals interacting with one another. In order to learn about a species, observations and experiments have to be conducted in both aforementioned parameters. Behavioral observations of intraspecific interactions can be studied by observing competition between individuals of the same species over a particular limited resource. An example of such a limited resource is the gastropod shell for hermit crabs. Empty gastropod shells are in very short supply and can most often be found at gastropod predation sites after a snail's death (Tricarico and Gherardi, 2007).

Animals living in the intertidal zone, such as hermit crabs, need to adapt to environmental and physical stressors present in the intertidal zone (Shives, 2010). Hermit crabs are able to protect themselves from these stressors by occupying empty gastropod shells, which they use as their homes (Halpern, 2004). These invertebrates inhabit the shells to protect their soft abdomens (Hazlett, 1970). They are very selective in choosing a shell that is not too small nor too large, and will constantly change shells to find one that has the best fit (Hazlet, 1981). Hermit crabs gain protection from predation, desiccation, and other hermit crabs by occupying a gastropod shell (Conover, 1978). The size, quality, and quantity of available gastropod shells limit a hermit crab's growth rate, reproduction, and population size (Fotheringham, 1976). Hermit crabs are limited by the number of shells released into the intertidal zone by freshly killed or naturally dying gastropods, since hermit crabs do not kill and remove snails from their shells (Laidre, 2011).

The hermit crab, *Pagurus samuelis*, is found in the upper and middle intertidal zones between the Vancouver Islands in British Colombia and the Punta Eugenia in Baja California, on protected rocky shore tide pools (Morris et al., 1962). *P. samuelis* prefers to inhabit *Chlorostoma funebralis* shells (Mesce, 1993). The *P. samuelis* crab is more resistant to the effects of exposure to air and sunlight than any other California species of hermit crabs (Morris et al., 1962). Adult *P. samuelis* are usually more active from the late afternoon until dawn and are rather inactive during the day (Morris et al., 1962).

This experiment had three treatments to test for shell selection and recognition. Treatment 1 allowed a shell-less hermit crab the selection of his own shell or another matched shell of the same species previously inhabited by another *P. samuelis*. Treatments 2 and 3 tested the preference of protection over the preference of selection. Treatment 2 specifically tested whether two shell-less hermit crabs would choose the shell in closest proximity to themselves that was previously inhabited by another hermit crab whose shell is very similar to its original, or choose their own original shell that was farther away in proximity and next to another *P. samuelis* that might be an opponent and cause a fight. Treatment 3 tested whether two shell-less hermit crabs chose their own original shell closest in proximity to themselves, or the shell of an opponent closest in proximity to the opponent. This experiment thus determined *P. samuelis'* choice of shell, its own shell or the shell of another, when tested individually and in pairs of the same sex.

The purpose of this experiment was to test intraspecific competition of *P. samuelis* over shell selection and recognition. *P. samuelis* was observed to prefer its own shell or a shell with a matched aperture previously inhabited by another individual of the same species of hermit crab. The gastropod shells originally inhabited by the hermit crabs were all *C. funebralis*.

Materials and methods

2.1. Specimen Collection

Pagurus samuelis were collected locally from in the tide pools on the northern side of Horseshoe Cove in the Bodega Marine Reserve, Bodega Bay, California. Both female and male *P. samuelis* that occupied *Chlorostoma funebralis* gastropod shells were collected. Collections were made in May and early June and hermit crabs were maintained individually in 19.5 cm x 11 cm x 12.5 cm cubicles immediately after being collected. The cubicles were made of perforated plastic partitioned boxes that were immersed in a filtered flow through seawater table. However, some hermit crabs were doubled and tripled up due to limited cubical space. It should be noted that only hermit crabs of different shell and body sizes were doubled and tripled up and placed in cubicles to eliminate the ability of shell switching. Hermit crabs of similar shell and body sizes were not doubled up in the cubicles.

The hermit crabs were kept in seawater at an average temperature of 13 °C. Crabs were fed thawed baitfish once a week. Hermit crabs were held in the cubicle and used for the behavioral studies within one to two weeks of being collected from the field. The majority of the behavioral studies occurred within one week of hermit crab collection. Each hermit crab was measured once and only used for one trial then released back to the collection site after the treatment was completed.

2.2. Shell and Pagurus samuelis measurements

P. samuelis were given a few days to adjust in the cubicles after being collected before the shell and body measurements were taken. For the shell and body and measurements, *P. samuelis* was extracted from its shell by intermittently applying heat to the apex of the shell using the tip of a soldering iron. The hermit crab would then crawl out of its shell as the shell heated up. *P. samuelis* was then placed in seawater and allowed to rest while the shell measurements took place. After the shell measurements were taken, the hermit crab was sexed and had its body size measured.

The shell was measured for weight, length, width, aperture size, and overall shell quality. The shell was also photographed using a Sony cyber-shot digital camera. Each shell was weighed using a digital scale. The length, width, and largest and smallest perpendicular diameters of the aperture were measured using a digital caliper (Figure 1). Additional notes were taken on the shell's quality by noting the number of holes, size of the holes, and the hole's location. The condition of the base of the shell was also observed for chips and was recorded in the additional notes.

P. samuelis was sexed under a stereoscope by identifying whether or not the gonopore was present on the 3rd leg under 6x or 25x magnification. If the gonopore was present, then that hermit crab was a female (Figure 2). Males have their gonopore located on the 5th leg which was not checked in this procedure. The body length of *P. samuelis* was measured from the anterior of the head to the posterior of the abdomen using standard ruler. After measurements were taken, shells were returned to the original hermit crab.

2.3. Shell Selection Treatment Set-up

P. samuelis of the same sex were paired for the treatment trials. The individuals in each pair were selected by having the closest sized aperture cross section and abdomen length to one another. The order of female pairs and male pairs were randomly selected by using a randomly selecting number generator for the order of the trials. One individual in each pair was also randomly selected using the random number generator to be the tested hermit crab for Treatment 1. For Treatments 2 and 3, the random number generator was used to select which hermit crab was Crab 1 and Crab 2, which is what determined the location of where the hermit crabs and shells were placed in the circular arena.

The hermit crabs were tested in a glass circular arena with a 19 cm diameter that was filled with 5 cm of seawater from the flow through seawater system. Shells were placed 1 cm to 2.5 cm away from the arena wall towards the center. Small shells with small hermit crabs were placed closer to the wall and large shells with large hermit crabs were placed farther away from the wall. Both shells were placed so that the opening was facing the center of the arena. A 36 cm x 35 cm x 49 cm (length x width x height) cardboard box with the bottom removed was placed over the circular arena to block shadows and prevent outside movement distractions for the hermit crabs. A led light was placed above the observation arena and box for light. Hermit crabs were placed in the same direction facing 90 degrees away from both shells for Treatment 1. For Treatment 2 and 3, the hermit crabs were placed facing the shell closest to them, 2.5 cm away from that shell. The first two trials of Treatment 1 were observed for 30 minutes, and 10 minutes was decided as the appropriate observation time period for the subsequent trials for the three treatments.

2.4. Shell Selection Treatment Procedure

Before the experiments took place, *P. samuelis* were given a few days to a week to recover from the shock of being collected, put in captivity and having their shells removed for measurements. For each experiment, *P. samuelis* was extracted from its shell by intermittently applying heat to the apex of the shell using the tip of a soldering iron. After being removed from its shell, *P. samuelis* was given a rest period of three to twenty minutes to adjust from the shock of being removed from its shell before being used for the treatments.

Treatment 1 consisted of one hermit crab and two shells placed on opposite sides of a circular glass arena. The hermit crab's own shell was placed on the right side 50% of the time and on the left side 50 % of the time. The hermit crab was placed in the center of the arena between both shells. Treatment 2 consisted of Crabs 1 and Crab 2 and both of their shells. In this treatment, Crab 1 was placed on the bottom right and Crab 2 on the bottom left while Crab 1's shell was placed on the top left and Crab 2's shell on the top right. Treatment 3 consisted of Crab 1 and Crab 2 and both of their shells. In this treatment, Crab 1 was placed on the bottom left and Crab 2 on the bottom right while Crab 1's shell was placed on the top left and Crab 2's shell on the top right. Care was taken in order to remove the bubbles trapped in the shells when the shells were placed in the water in the circular arena.

The notes that were recorded were: 1) The time lapse from removing the crab's shell to the start of the treatment; 2) The time it took for the hermit crab to select its first shell; 3)Which shell was selected by each individual crab; 4) The number of times each crab switched shells; 5) Which shell the hermit crab was occupying at the 10^{th} minute of the trial experiment; 6) Behavioral notations such as actions the crabs had individually or together; 7) The presence or absence of eggs for each female hermit crab.

2.5. Data Analysis

Data were analyzed using R and JMP statistical software. The percentages of the times the hermit crab chose its own, other, or neither shell was calculated for the first selected shell and at the shell chosen after 10 minutes. Chi-squared tests were performed and p-values were used to determine statistical significance.

Results

The percentage of times the hermit crabs selected its own, other, or neither shell at the time first selected and at 10 minutes was calculated for all three treatments. A Chi-squared test was used to determine the p-values that compared the hermit crab's selection of its own and other shell for both the females and males for all three treatments using R. The females and male hermit crabs were analyzed separately and the crab's selection for neither shell was not included in the Chi-squared test. Another Chi-squared test was performed to determine the p-values that compared the hermit crab's shell selection, which was compared to both sexes for all three treatments using JMP statistical software. For the Chi-squared test performed using JMP, the hermit crab's shell selection for neither shell was not included, however both sexes were analyzed together.

For Treatment 1, at the time the hermit crab first selected its shell, 70% of females chose their own shell while 30% chose the other shell ($p=0.07364$) (Figure 3). For Treatment 1, at ten minutes, 65% of females chose their own shell while 35% chose the other shell ($p=0.1797$) (Figure 4). For Treatment 1, at the time the hermit crab first selected its shell, 50% of males chose their own shell while 45% chose the other shell, and 5% chose neither shell ($p=0.8185$) (Figure 3). For Treatment 1, at ten minutes, 50% of males also chose their own shell while 45% chose also the other shell, and 5% also chose neither shell (p = 0.8185) (Figure 4). The p-value was 0.4470 under a Chi-squared test for the shell first selected in Treatment 1 of the hermit crab's choice of its own shell and other shell compared to the hermit crab's sex. The p-value was 0.5663 under a Chi-squared test for the shell selected at 10 minutes in Treatment 1 of the hermit crab's choice of its own shell and other shell compared to the hermit crab's sex.

For Treatment 2, at the time the hermit crab first selected its shell, 44.1% of females chose their own shell while 47.1% chose the other shell, and 8.8% chose neither shell (p=0.8575) (Figure 5). For Treatment 2, at ten minutes, 44.1% of females chose their own shell while 44.1% chose the other shell, and 11.7% chose neither shell (p=1) (Figure 6). For Treatment 2, at the time the hermit crab first selected its shell, 39.5% of males chose their own shell while 55.2% chose the other shell, and 5.3% chose neither shell (p=0.5164) (Figure 5). For Treatment 2, at ten minutes, 45% of males chose their own shell while 50% chose the other shell, and 5% chose neither shell (p=0.8575) (Figure 6). The p-value was 0.7721 under a Chi-squared test for the shell first selected in Treatment 2 of the hermit crab's choice of its own shell and other shell compared to the hermit crab's sex. The p-value was 0.5537 under a Chi-squared test for the shell selected at 10 minutes in Treatment 2 of the hermit crab's choice of its own shell and other shell compared to the hermit crab's sex.

For Treatment 3, at the time the hermit crab first selected its shell, 60% of females chose their own shell while 31.4% chose the other shell, and 8.6% chose neither shell (p=0.106) (Figure 7). For Treatment 3, at ten minutes, 62.9% of females chose their own shell while 28.6% chose the other shell, and 8.6% chose neither shell (p=0.04819) (Figure 8). For Treatment 3, at the time the hermit crab first selected its shell, 50% of males chose their own shell while 42.5% chose the other shell, and 7.5% chose neither shell (p=0.6219) (Figure 7). For Treatment 3, at ten minutes, 58.3% of males chose their own shell while 33.3% chose the other shell, and 8.3% chose neither shell (p=0.139) (Figure 8). The p-value was 0.6674 under a Chi-squared test for the shell first selected in Treatment 3 of the hermit crab's choice of its own shell and other shell compared to the hermit crab's sex. The p-value was 0.8721 under a Chi-squared test for the shell selected at 10 minutes in Treatment 3 of the hermit crab's choice of its own shell and other shell compared to the hermit crab's sex.

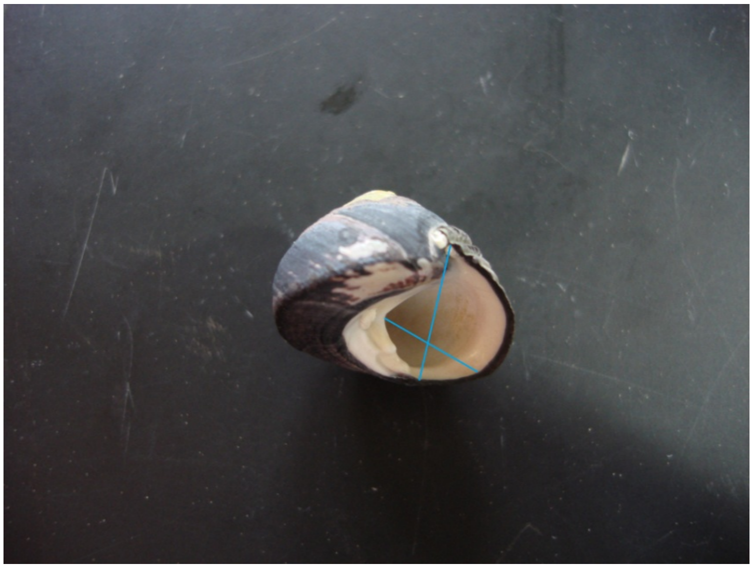

Figure 1. Image of the cross section measured of the shell's aperture

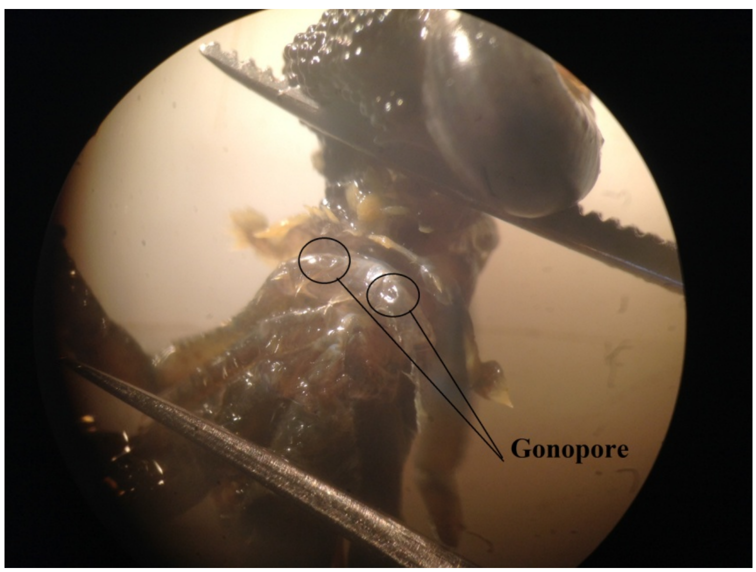

Figure 2. Image of a female hermit crab with the gonopore on the third leg. Eggs are shown on the hermit crab's abdomen

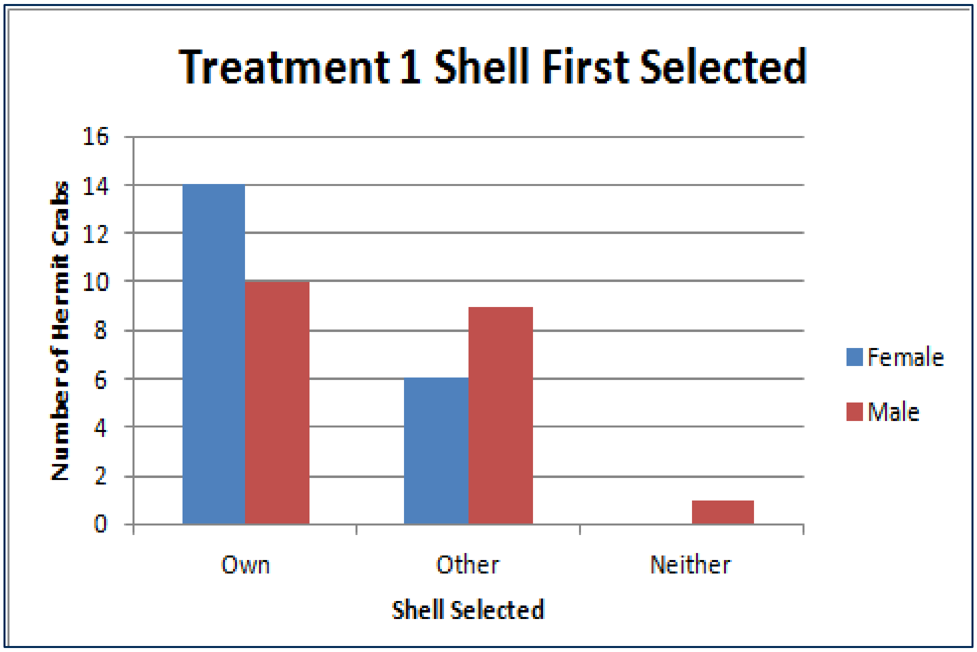

Figure 3. The number of hermit crabs that first selected their own, other, or neither shell in Treatment 1

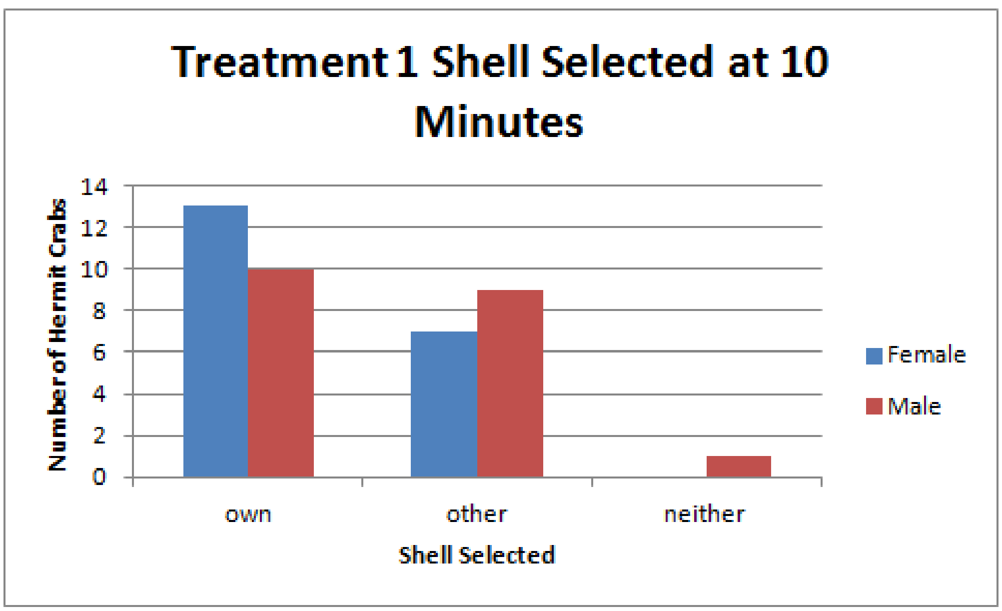

Figure 4. The number of hermit crabs that selected its own, other or neither shell in Treatment 1 at 10 minutes

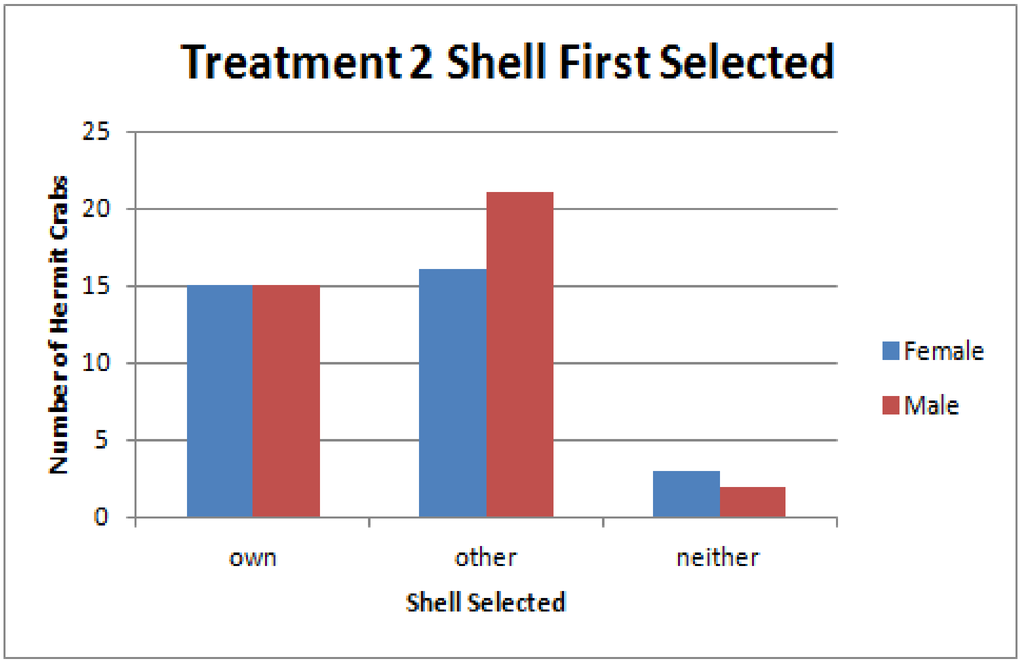

Figure 5. The number of hermit crabs that first selected its own, other, or neither shell in Treatment 2

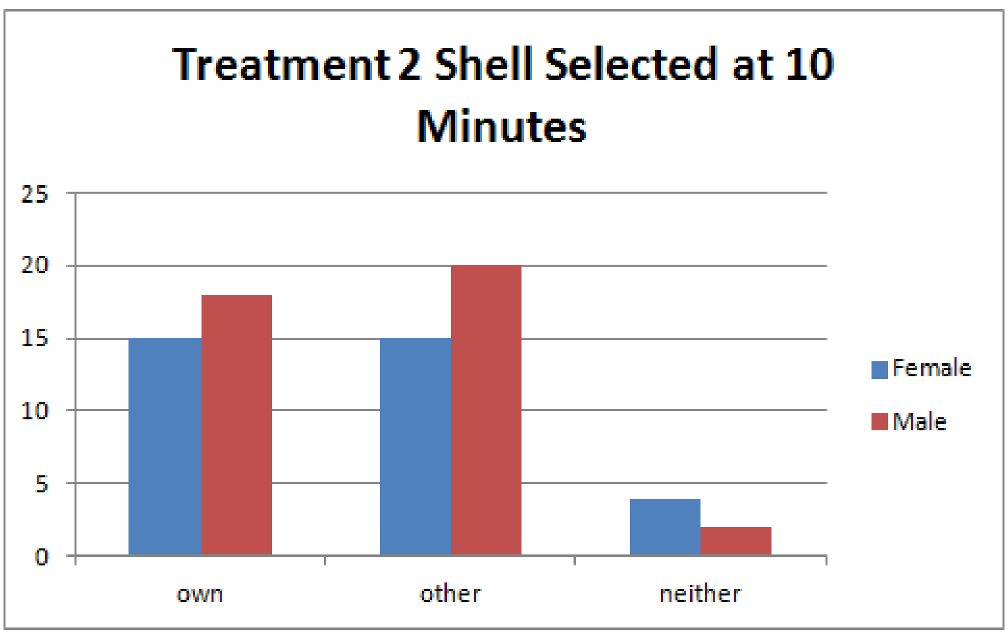

Figure 6. The number of hermit crabs that selected its own, other or neither shell in Treatment 2 at 10 minutes

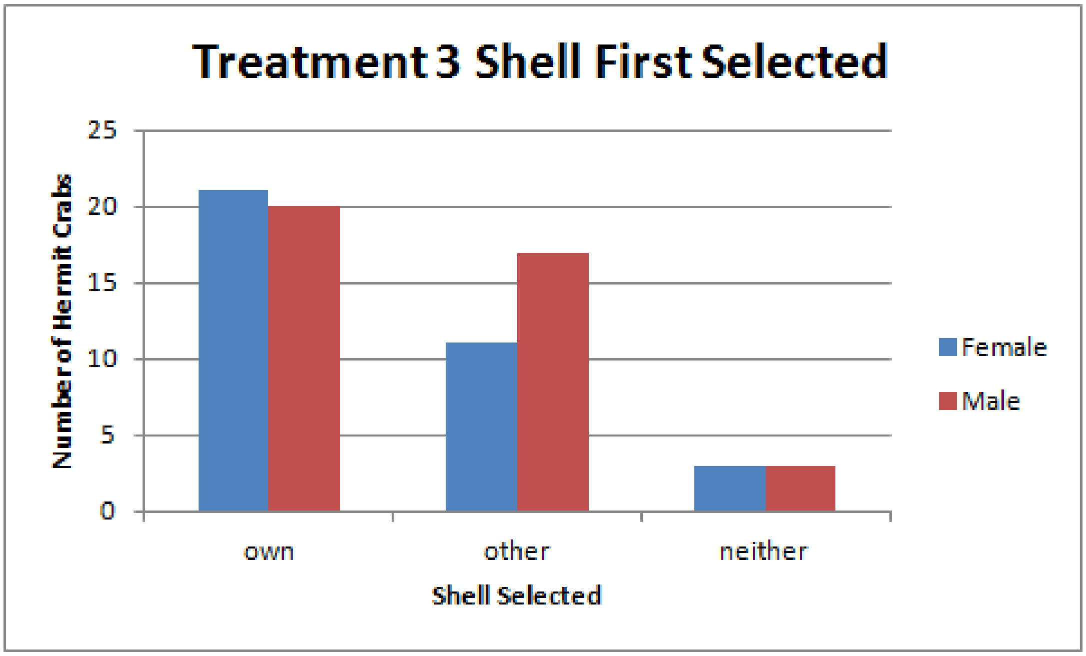

Figure 7. The number of hermit crabs that first selected its own, other, or neither shell in Treatment 3

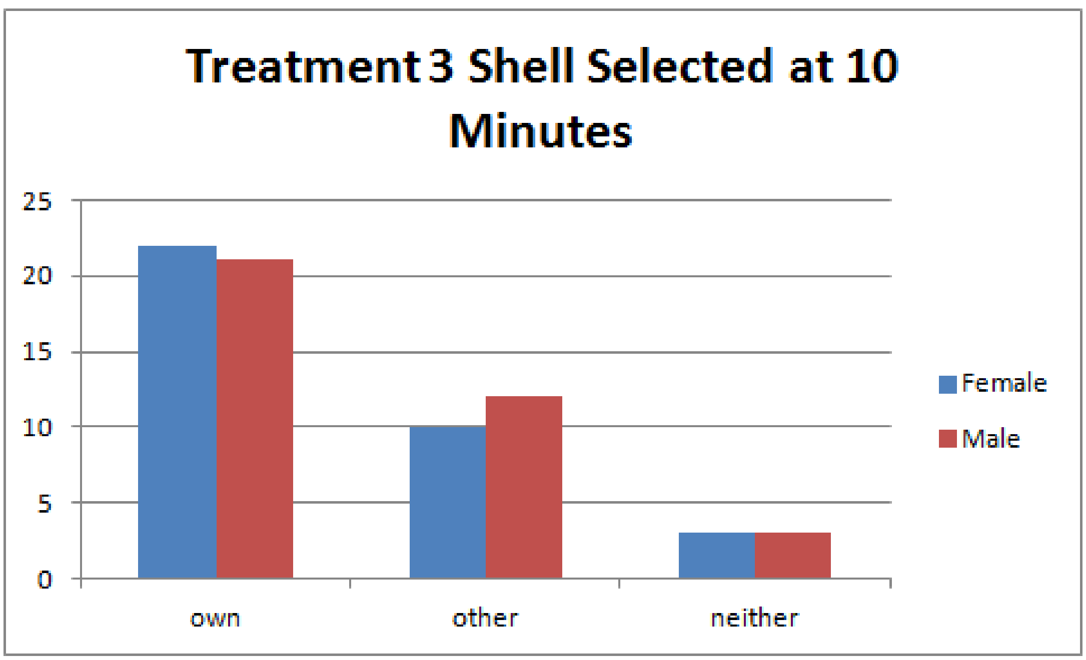

Figure 8. The number of hermit crabs that selected its own, other or neither shell in Treatment 3 at 10 minutes

Discussion

The data were not statistically significant in Treatment 1, however, females had an initial preference for their own shell and males had a lack of shell preference. The data were not statistically significant in Treatment 2, however, both females and males initially preferred the other hermit crab's shell but later the proportion of males preferring their own shell increased. In Treatment 3, the data were significant for the female's shell choice at 10 minutes where the females significantly preferred their own shell over the shell of the other hermit crab. The males in this treatment initially did not have a preference for either shell but by 10 minutes, an increased preference for their own shell was observed.

Overall, though not statically significant, hermit crabs initially prefer the shell closest to them for protection over their own shell, but later at 10 minutes prefer their own shell, as indicated by later switching to their own. This shows that the location of the shell matters to a hermit crab when it is in the presence of another hermit crab, which is especially notable in males.

Benoit (1997), found a statistical significance in *P. samuelis'* preference towards its own shell. Benoit (1997), assumed that *P. samuelis'* sex did not matter based on the findings by Brown, Hazlett, and Haster for the *Calcinus tibicen* hermit crab (1993). The results observed in the research described in this supports Benoit's assumptions that *P. samuelis'* sex does not make a difference in shell selection for this hermit crab.

The hermit crabs preferred to obtain the shell closest to them when the hermit crabs were in the presence of a conspecific. These finding shows that protection is more desirable than their preference of their own shell.

Considering gastropod shells are very important to the hermit crab's growth rate, reproduction, and population size, the ability of obtaining a shell as quickly as possible is crucial (Fotheringham, 1976).

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