

**Detecting patterns between anthropogenic shell choice and predation, competition,  
sex or size in the hermit crab *Pagurus granosimanus***

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# Detecting patterns between anthropogenic shell choice and predation, competition, sex or size in the hermit crab *Pagurus granosimanus*

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## ABSTRACT

Marine debris has many impacts on intertidal ecosystems, and hermit crabs across various species and locations have been photographed using marine debris as shells. While hermit crab shell selectivity is a well-studied behavior, little is known about why hermit crabs are using anthropogenic shells. This paper tested for a relationship between bottle cap shell selection and four variables: competition, predation, sex, and size. *Pagurus granosimanus* hermit crabs were collected from three locations on San Juan Island, Washington and research was conducted at Friday Harbor Laboratories. Experiments simulated the presence of competition and/or predation and observed unshelled crabs as they selected among various gastropod shells and plastic bottle caps. The results indicated no significant relationships between shell preference and competition, predation, sex, and size. The paper makes suggestions for future research on both why hermit crabs are using marine debris and how this behavior may impact hermit crab ecology.

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## INTRODUCTION

Hermit crabs are known for their close association with gastropod shells, which play a role in crab predation avoidance, mate selection, and growth rate. Hermit crabs have expressed preferences for larger, thicker shells with a greater aperture, which allow them to hide their whole body in their shell and avoid shell-crushing predators (Hazlett 1981). In addition, studies show that shell size and architecture impact a male's ability to find a mate (Contreras-Garduño & Córdoba-Aguilar 2006). Shells also play a role in hermit crab growth capacity and rate. Crabs in shells that are too small have exhibited significantly less growth than crabs in optimal shells (Fotheringham 1976). As such, shell selection is a highly studied and extremely indicative aspect of hermit crab health and behavior.

The anthropogenic impact on marine environments is evident through the documentations of hermit crab's using marine debris as shells. This phenomenon was documented in a study through iEcology (the use of digital content as a data source), which found 386 photos of individuals with artificial shells, representing 10 terrestrial species and 5 continents. Of the digital samples, 85% were using plastic materials (Jagiello et. al. 2024). Other scientific records of artificial shell use are limited to observations of singular individuals or peripheral mentions (Barreiros & Luiz 2009, Sharma 2018, De Carvalho-Souza et. al. 2018, Sasazuka et. al. 2019). Little is known about why this phenomenon is occurring, and no observational or experiential studies on this have been published. Acrylic 3D-printed shells have been used to test shell architecture and preference in hermit crab *Pagurus longicarpus*. Of these shells, half were coated in a CaCO<sub>3</sub> coating, and 14 out of 19 crabs preferred coated shells (Gravel et. al. 2004). This raises the question of why hermit crabs are using plastic shells despite showing a preference for organic materials, a behavior with unknown implications on hermit crab ecology.

This paper seeks to understand why hermit crabs are selecting anthropogenic shells by testing for patterns between the selection of plastic bottle cap shells and four independent variables: predation, competition, sex, and size. Hermit crab *Pagurus granosimanus* was selected as a model species due to its distinguishable features and abundance across the Western coast of North America. The experiment placed unshelled crabs in the presence of either predation, competition, both, or neither and observes whether they select a gastropod shell, bottle cap, or neither. Time of shell selection, shell type, sex, and size were recorded. The experiment is designed to test four hypotheses: 1) *P. granosimanus* will have a preference for *Nucella* shells or bottle caps that differs in the presence of predators; 2) *P. granosimanus* will have a preference for *Nucella* shells or bottle caps that differs in the presence of other crabs; 3) *P. granosimanus*

will have a preference for *Nucella* shells or bottle caps that differs by sex; and 4) *P.*

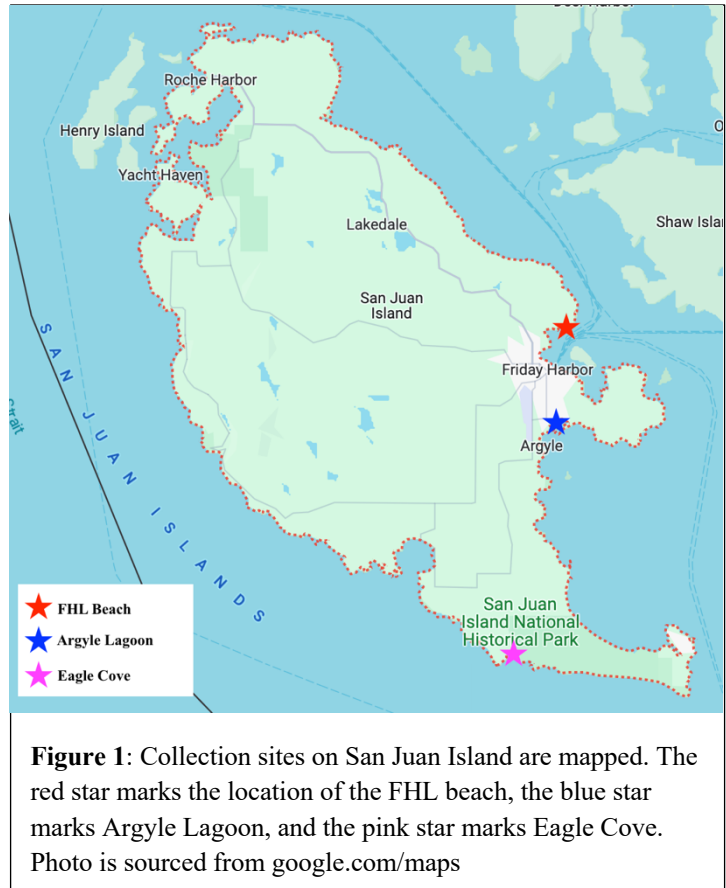
*granosimanus* will have a preference for *Nucella* shells or bottle caps that differs by size.

Additionally, in the treatments where competition is present, I hypothesize that *Nucella* shells will be selected earlier in the trials, and bottle cap shells will be selected later. Future research can use these findings when working to understand the impacts of anthropogenic shell use and how this behavior may disrupt ecological processes.

## MATERIALS AND METHODS

Forty-five *P. granosimanus* individuals were collected from the Friday Harbor Labs (FHL) beach, Argyle Lagoon,

and Eagle Cove on San Juan Island, Washington (Figure 1). Individuals had a shield length ranging from 4.0 to 10.5 mm. Most samples were originally found in shells from the *Nucella* genus, except for four crabs that were found in *Littorina* shells. A circular tank with 1.0 m diameter was filled with 0.15 m of water and hooked up to a constant flow of seawater. Crabs were held in the tank for one week to acclimate. Rocks and algae were also placed in the tank to increase enrichment (Hills & Webster 2022). During this time, a preliminary test was run with ten unshelled crabs, which were placed in a separate Tupperware container with black bottle caps of various diameters and depths to test if *P. granosimanus* would use the caps. In the final



experiment, bottle caps of two sizes were used [1.5 cm diameter, 1.5 cm deep and 1.4 cm diameter, 1.3 cm deep]. Crabs were fed about 90 grams of whole dead scallops and mussels twice a week.

After one week, all 45 crabs were removed from their original or preliminary test shell by applying the heat of an ethanol lamp about 0.5 cm away from the apex of their shell (Figure 2, Burciaga & Alcaraz 2023). Forceps were used to grab the siphon notch of the shell and hold the crab 0.5 cm from the flame until the crab crawled out voluntarily. This process took about five minutes for each crab. Crabs were then sorted by sex, which was determined by looking for ventral gonopores, which are present only in females. All females happened to be brooding eggs at the time of the experiment. Crabs were unshelled until there were 20 of each sex. The three remaining crabs were kept in case any unshelled individuals died during the experiment.

Twenty-four bottle cap shells were labeled alphabetically and twenty-four *Nucella lamellosa* (frilled dogwinkle) shells were labeled numerically, both using nail polish.



**Figure 2:** Crabs were removed from their shell by applying heat to the apex of the shell. Forceps grasped the shell siphon and held the crab 0.5 cm from the flame of an ethanol lamp.

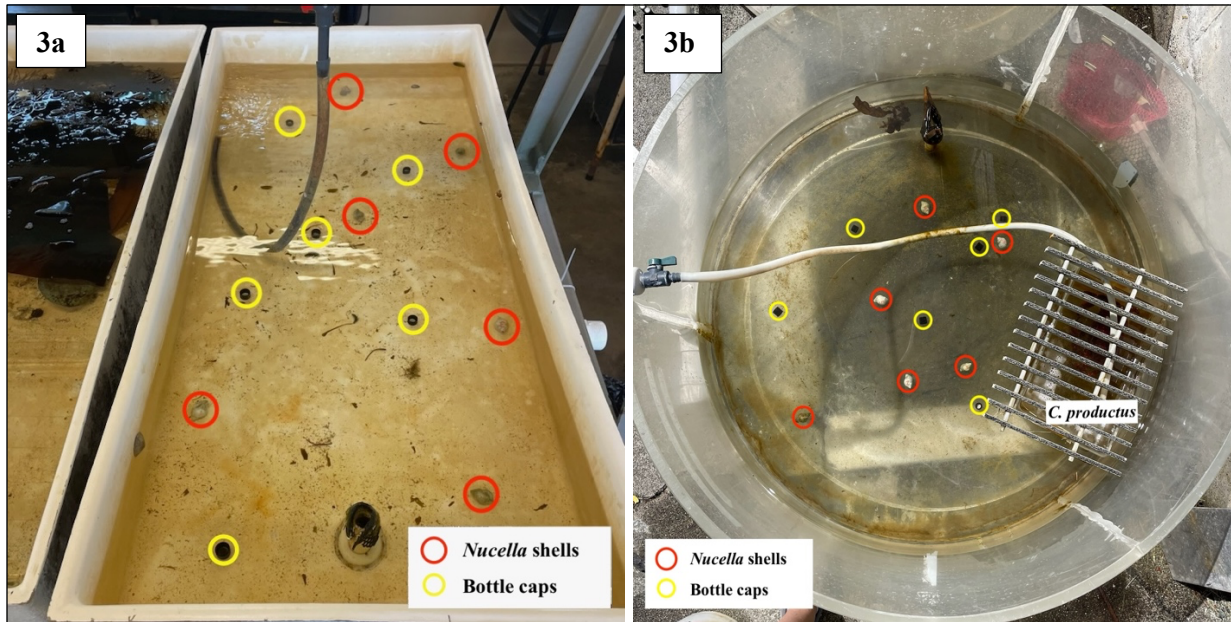
### ***Experiment 1: Shell choice vs competition***

Twenty trials were conducted under each Treatments 1 and 3, which simulated a non-competitive environment by allowing crabs to select a shell in solitude. Ten trials used male crabs and ten trials used female crabs. In a tank with the same measurements as the acclimation tank and constant seawater flow, four *Nucella* shells and four bottle caps were randomly scattered around the tank. For

each crab, sex and shield length was recorded. Shield length was used as a metric for hermit crab size (Turra & Leite 2004). Next, the crab was placed in the center of the tank and a timer was started. The trial stopped once either the crab chose a shell, or ten minutes had passed. The chosen shell type and time of event (in seconds) was recorded. Shells that were not selected during one trial remained in the tank for the next trial, while the previously chosen shell was replaced.

Four trials were conducted under Treatments 2 and 4, which simulated a competitive environment by placing ten unshelled crabs in a tank at a time. For each of the four trials, five males and five females were used. In the same tank used for Treatments 1 and 3, six *Nucella* shells and six bottle caps were randomly scattered. Six of each shell type was used to ensure that there was competition, but that a majority population could be in either shell type. Shells 1-6 and A-F were used in trial 1, 7-12 and G-L were used in trial 2, etc. so that new shells were used for each trial. This was intended to control for chemical cues that previous inhabitants may have left behind in the shells, while the labels allowed us to differentiate between individuals after they had chosen shells.

The first five males and five females were placed in the center of the tank and a timer was started. When each crab selected a shell, it was immediately removed from the tank, and the time (in seconds) and shell number/letter was recorded. Crabs that chose bottle caps could be removed from the shell to be measured and sexed. Crabs that chose *Nucella* shells were placed in a separate container. The trial was cut off at 20 minutes, and the remaining unshelled crabs were measured and sexed. This process was repeated three more times with ten new crabs each time. Afterwards, crabs in *Nucella* shells were removed using the ethanol lamp method (Figure 2) so that sex and shield width could be recorded.



**Figure 3a:** Set up for T1 and T2 where predators are not present. Six *Nucella* shells and six bottle caps are scattered around the tank. Note the different tank due to weather conditions. **Figure 3b:** Set up for T3 and T4 where a predator was present. *C. productus* was placed in a smaller container with a grate place over the top. Six *Nucella* shells and six bottle caps are scattered around the tank.

### ***Experiment 2: Shell choice vs predation***

Treatments 1 and 2, which included 20 non-competitive trials and 4 competitive trials, simulated no predation. Nothing else was present in the test tank aside from the six *Nucella* shells and 6 bottle caps (Figure 3a). Experiments were set up and data was collected as previously described. For Treatments 3 and 4, a red rock crab *Cancer productus* was placed in a smaller plastic container with holes drilled in the side, which was placed within the test tank to simulate the presence of a predator (Figure 3b). Experiments were otherwise ran as previously described. Table 1 describes the predator and competition conditions in each treatment.

For statistical analysis, shell types were categorized as snail, cap, and none. Frequencies of each shell type were calculated in relation to sex, predation, and competition, respectively. Chi-square tests were run to test for significance between shell choice and each of the other

categorical variables (i.e. shell choice and sex). Frequencies were then used to calculate the percentage of each group that chose a bottle cap and the percent that chose a *Nucella* shell. Percentages were graphed in bar plots, excluding the percentage of individuals that did not choose a shell by the end of the trial. Crab shield width was used as a metric for size and was graphed by shell type using box and whisker plots. Significance between the type of shell chosen and the size of individuals was tested using ANOVA. Shell type and time to select a shell in treatments 3 and 4 were also plotted in box and whisker plots. Significance between type of shell chosen and time to select the shell was tested using ANOVA.

**Table 1:** The table describes the predation and competition conditions in each trial. A yes in the predation column means *C. productus* was present in the test tank, while a yes in the competition column means there were 10 crabs in the test tank during the trial. For each treatment, the percent of individuals that chose bottle caps (rather than a *Nucella* shell or no shell). The average percent of individuals that chose a bottle cap across all trials is also shown.

| Treatment | Predation | Competition | % in Caps |
|-----------|-----------|-------------|-----------|
| T1        | no        | no          | 18.75%    |
| T2        | no        | yes         | 18.75%    |
| T3        | yes       | no          | 40.00%    |
| T4        | yes       | yes         | 18.75%    |
| AVG       |           |             | 24.06%    |

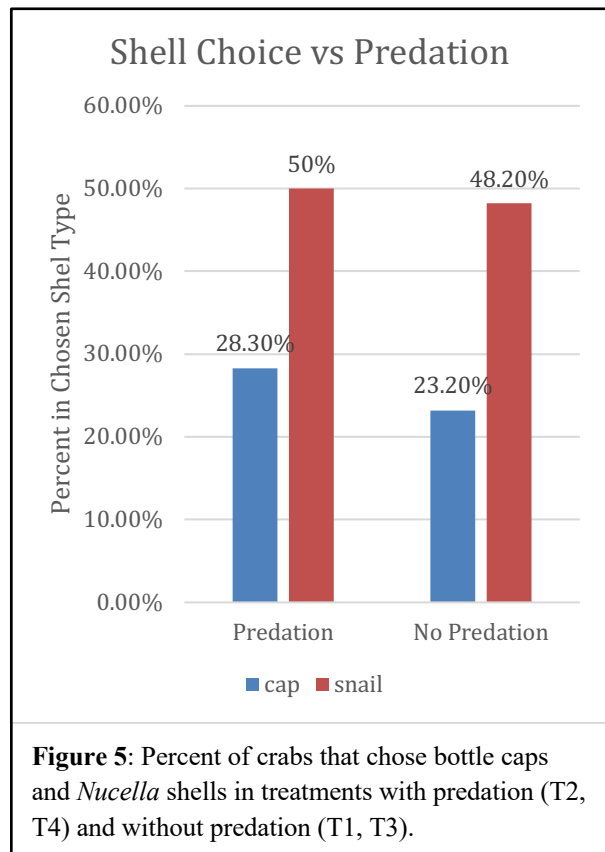
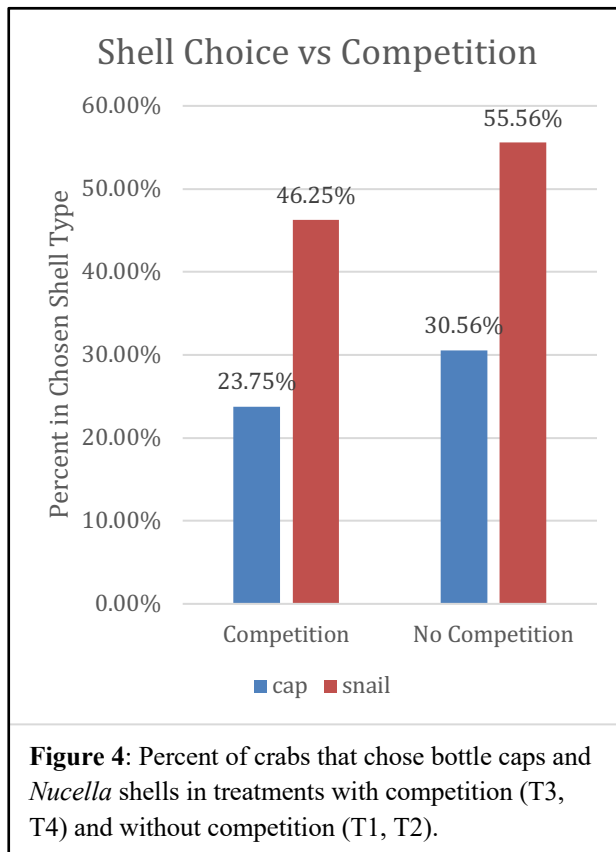
## RESULTS

### *Shell Choice vs Competition*

Figure 4 compares the percentages of crabs that chose bottle caps and *Nucella* shells in competitive vs non-competitive treatments. 30.0% of crabs that were in competitive trials failed to choose a shell by the end of the trial, while only 13.9% of crabs in non-competitive trials did not choose a shell (not graphed). Thus, in the non-competitive trials, a higher percentage of crabs chose either a bottle cap or *Nucella* shell compared to competitive trials. The Chi Square test yielded a p-value of 0.1771.

### Shell Choice vs Predation

Percentages of the individuals that chose bottle caps and *Nucella* shells in Treatments 1 and 2 are compared to the percentages of the individuals that chose bottle caps and *Nucella* shells in Treatments 3 and 4 (Figure 5). A higher percentage of crabs chose *Nucella* shells compared to bottle caps under both conditions. In the predator treatments (T3 and T4), 28.3% of individuals chose a bottle cap, while 23.2% chose a bottle cap in trials without a predator. The Chi Square test generated a p-value of 0.6471.

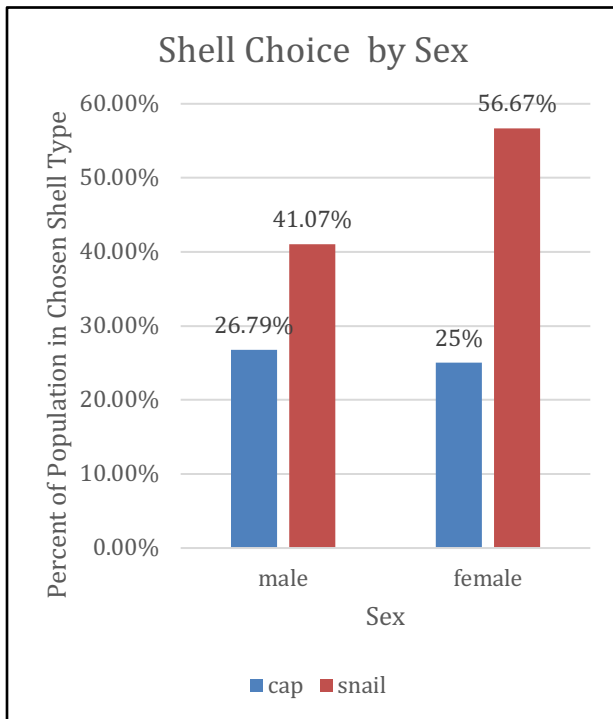


### Shell Choice vs Sex

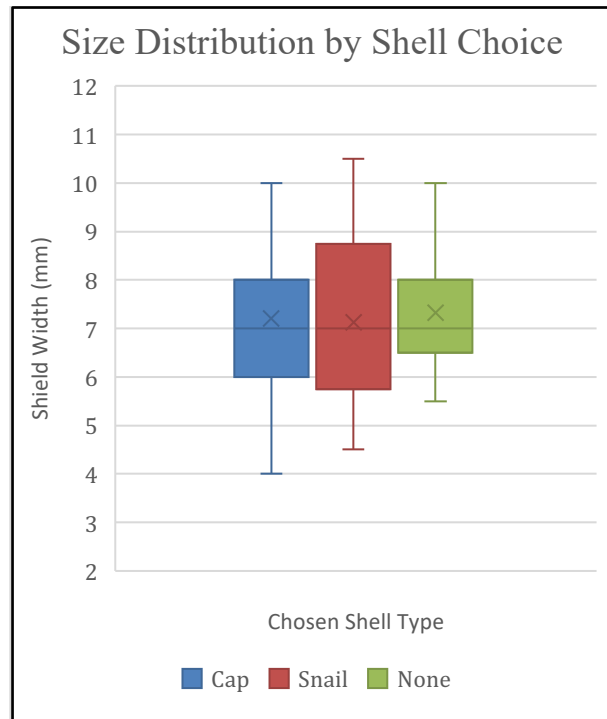
Figure 6 shows the percentage of males that chose bottle caps and *Nucella* shells compared to the percentage of females that chose bottle caps and *Nucella* shells. 56.7% of females chose *Nucella* shells, while 41.1% of males chose *Nucella* shells. About 25% of both sexes chose a bottle cap. It is notable that 32.1% of males failed to choose a shell, while only 18.3% of females did not choose a shell. The Chi Square test yielded a p-value of 0.1600.

### Shell Choice vs Size

The size distribution of crabs with the chosen shell types of bottle cap, *Nucella* shell, and no shell are compared through box and whisker plots in Figure 7. Crabs of all three shell choices had an average shield length of 7.0 mm. The smallest crab measured 4.0 mm and chose a bottle cap. The largest crab measured 10.5 mm wide and chose a *Nucella* shell. The ANOVA test found no significance between the size distributions and generated a p-value of 0.8523.



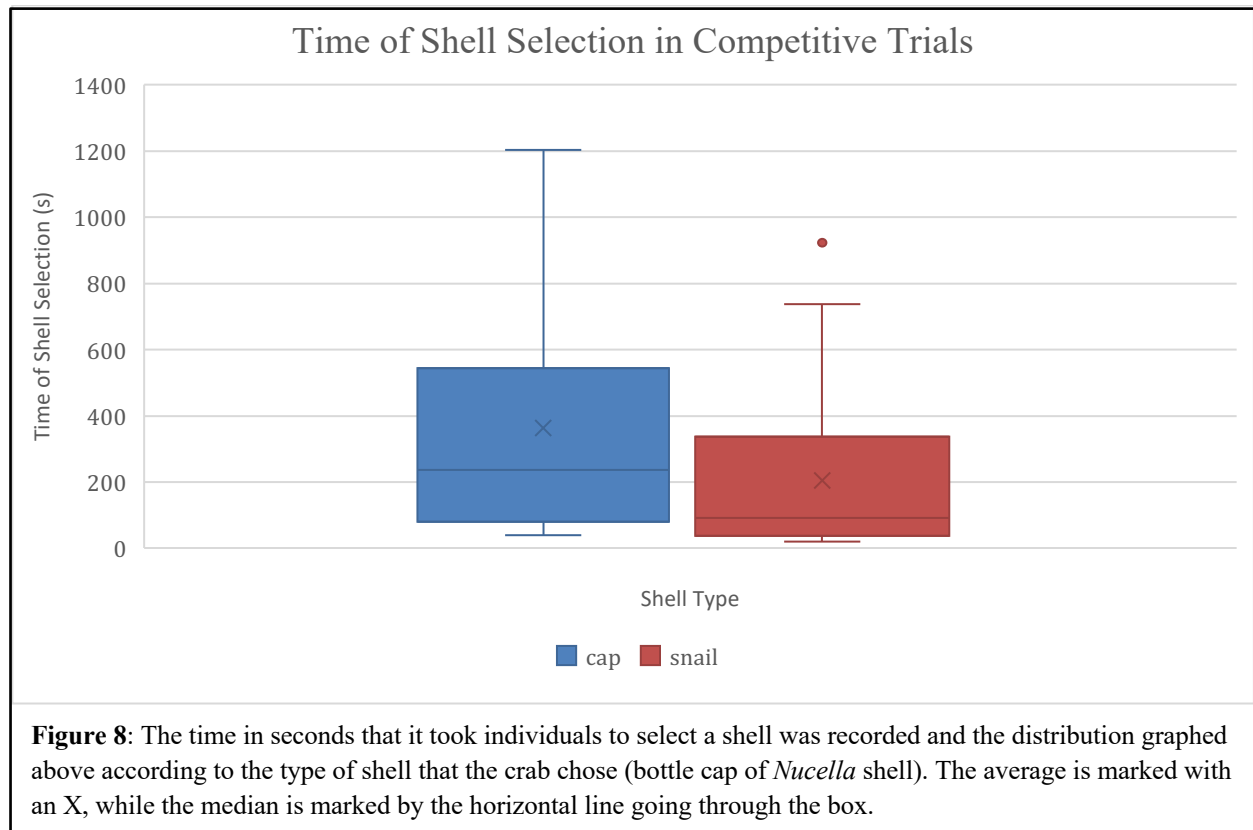
**Figure 6:** Percent of male vs female crabs that chose bottle caps and *Nucella* shells.



**Figure 7:** Size distribution of crabs by their choice of shell. The average is marked by an X. The median is marked by the central horizontal line.

### ***Shell Choice and Time***

The time at which each crab placed their abdomen in a bottle cap or *Nucella* shell was recorded and plotted in Figure 8. On average, crabs that selected a bottle cap were in the shell at 363 seconds, while crabs that selected a *Nucella* shell did so in 205 seconds. The ANOVA test yielded a p-value of 0.06374.



## DISCUSSION

### ***Shell Choice vs Competition***

Hypothesis 1 expected to see a difference in shell preference between competitive (T2 and T4) and non-competitive treatments (T1 and T3). While a greater percentage of *P. granosimanus* did not select a shell in competitive treatments compared to non-competitive

treatments (Figure 4), crabs preferred *Nucella* shells over bottle caps under both conditions. There was no statistically significant relationship between the presence of competition and shell choice ( $p = 0.1771$ ). We failed to reject the null hypothesis.

### ***Shell Choice vs Predation***

Hypothesis 2 expected to see a difference in shell preference between treatments with a predator (T3 and T4) and without a predator (T1 and T2). Under both conditions, about half of the population chose a *Nucella* shell and about a quarter chose a bottle cap (Figure 5). No statistically significant relationship between simulated predation and shell choice was detected and we failed to reject the null hypothesis ( $p = 0.6471$ ). However, T1 and T2 were conducted in an indoor sea table rather than the designated outdoor test tank due to weather conditions. This inconsistency may have impacted results.

### ***Shell Choice vs Sex***

Hypothesis 3 expected males and females across the entire data set to have different shell preferences. A notably higher percentage of females chose *Nucella* shells compared to males (Figure 6), while a higher percentage of males failed to choose a shell compared to females. However, the statistical test found no significant relationship between sex and shell choice ( $p = 0.1600$ ).

### ***Shell Choice vs Size***

Hypothesis 4 expected to see a relationship between size distribution and shell choice. Of crabs who selected a bottle cap, *Nucella* shell, or no shell, all categories had a median shield

length of 7mm and statistically similar range (Figure 7). We failed to reject the null hypothesis ( $p = 0.8523$ ).

### ***Shell Choice and Time***

We also hypothesized that *P. granosimanus* would select *Nucella* shells sooner than bottle caps in competitive treatments (T2 and T4) as higher commodity shells would be selected first. Figure 8 does show that the median time to select a *Nucella* shell was sooner than the median time to select a bottle cap. However, we failed to detect statistical significance and failed to reject the null hypothesis ( $p = 0.06374$ ).

While our experiment yielded no significant relationship between shell choice and any of the four variables tested, *P. granosimanus* may be selecting bottle caps due to another variable that was not tested. Hermit crabs are known to use various sensory tools to find shells, such as vision and chemical cues, which may be impacted by environmental changes in temperature, pH, and microplastic exposure (Suárez-Rodríguez et. al. 2023, McDaid et. al. 2023). Some studies even hypothesize that hermit crabs select plastic shells by sensing the chemical compound dimethyl sulfide (DMS) that is emitted from marine plastic (Jagiello et. al. 2024, Savoca et. al. 2016) Alternatively, anthropogenic shell use may be entirely random and a reflection of hermit crab resource evaluation (Turra & Gorman 2014).

Some aspects of the experiment did impact hermit crab health, and consequently may have impacted the data. The ethanol lamp method used to remove hermit crabs from shells resulted in some casualties and left some crabs with burns on their abdomen, and potential mental distress. Some crabs were removed from their shells up to 3 times in between treatments,

while crabs that did not choose a shell were removed less often. Crabs may have selected shells differently based on their individual experience (Turra & Leite 2003).

Ideally, new crabs would be used for each trial, instead of using the same 40 crabs for each treatment to ensure that experiences in previous trials are not impacting an individual's behavior. In future experiments, crabs should be collected, given a set time to acclimate to tank conditions in their original shell, removed from shell, then immediately tested. After running a trial, the crab should be rehabilitated with a new shell and time to acclimate. Afterwards, rehabilitated crabs should be released rather than being used for another trial. This was not possible given the limitations of time and sample size.

In addition, male crabs were held in containers of ten crabs between trials. Male crabs often exhibited aggressive behaviors, resulting in injuries from fighting. Further research should plan to separate crabs in individual tanks. With the limited space available, it was not possible to separate 20 crabs into separate containers. Trials were still run using injured crabs, which may have impacted the shell selection process.

In conclusion, no significant relationships between shells choice and competition, predation, sex, or size were found. However, it is notable that 24.06% of crabs across the whole experiment selected a bottle cap shell (Table 1). Crabs exhibited a clear capability to choose marine debris, even when organic shells were present. Because shells play such a significant role in hermit crab ecology, this should be studied more with a bigger sample size and more controlled environment. Additional research should also investigate how marine debris-based shells impact hermit crab growth, mating, and predation avoidance, and work to understand the ecological consequences of anthropogenic shell use.

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## REFERENCES

- Barreiros, J. P., & Luiz, O. J. (2009). Use of plastic debris as shelter by an unidentified species of hermit crab from the Maldives. *Marine Biodiversity Records*, 2. <https://doi.org/10.1017/s1755267208000377>
- Burciaga, L. M., & Alcaraz, G. (2023). Metabolic and behavioural effects of hermit crab shell removal techniques: Is heating less invasive than cracking? *Animal Welfare*, 32. <https://doi.org/10.1017/awf.2023.17>
- Contreras-Garduño, J., & Córdoba-Aguilar, A. (2006). Sexual selection in hermit crabs: A review and outlines of future research. *Journal of Zoology*, 270(4), 595–605. <https://doi.org/10.1111/j.1469-7998.2006.00182.x>
- de Carvalho-Souza, G. F., Llope, M., Tinôco, M. S., Medeiros, D. V., Maia-Nogueira, R., & Sampaio, C. L. S. (2018). Marine litter disrupts ecological processes in reef systems. *Marine Pollution Bulletin*, 133, 464–471. <https://doi.org/10.1016/j.marpolbul.2018.05.049>
- Fotheringham, N. (1976). Effects of shell stress on the growth of hermit crabs. *Journal of Experimental Marine Biology and Ecology*, 23(3), 299–305. [https://doi.org/10.1016/0022-0981\(76\)90027-7](https://doi.org/10.1016/0022-0981(76)90027-7)
- Gravel, B. E., Wong, P. Y., Starks, P. T., & Pechenik, J. A. (2004). The use of artificial shells for exploring shell preference in the marine hermit crab *Pagurus longicarpus* (Say). *Annales Zoologici Fennici*, 41, 477–485. <https://doi.org/https://www.jstor.org/stable/23736161>
- Hazlett, B. A. (1981). The behavioral ecology of Hermit Crabs. *Annual Review of Ecology and Systematics*, 12(1), 1–22. <https://doi.org/10.1146/annurev.es.12.110181.000245>
- Hills, A., & Webster, M. M. (2022). Sampling biases and reproducibility: Experimental design decisions affect behavioural responses in hermit crabs. *Animal Behaviour*, 194, 101–110. <https://doi.org/10.1016/j.anbehav.2022.09.017>

- Jagiello, Z., Dylewski, Ł., & Szulkin, M. (2024). The plastic homes of hermit crabs in the anthropocene. *Science of The Total Environment*, 913, 168959. <https://doi.org/10.1016/j.scitotenv.2023.168959>
- McDaid, A., Cunningham, E. M., Crump, A., Hardiman, G., & Arnott, G. (2023). Does microplastic exposure and sex influence shell selection and motivation in the common European hermit crab, *Pagurus Bernhardus*? *Science of The Total Environment*, 855, 158576. <https://doi.org/10.1016/j.scitotenv.2022.158576>
- Sasazuka, M., Hamasaki, K., & Dan, S. (2019). Shell utilization and shell-shedding behaviour by the land hermit crab *Coenobita spinosus*. *Ethology Ecology & Evolution*, 31(6), 544–556. <https://doi.org/10.1080/03949370.2019.1630013>
- Savoca, M. S., Wohlfeil, M. E., Ebeler, S. E., & Nevitt, G. A. (2016). Marine plastic debris emits a keystone infochemical for olfactory foraging seabirds. *Science Advances*, 2(11). <https://doi.org/10.1126/sciadv.1600395>
- Sharma, K. (2018). Hazardous hermit crab homes. *Frontiers in Ecology and the Environment*, 16(5), 287–287. <https://doi.org/10.1002/fee.1815>
- Suárez-Rodríguez, M., Kruesi, K., & Alcaraz, G. (2023). Hermit crabs use vision, olfaction, and eavesdropping to detect potentially available gastropod shells on a natural rocky shore. *Journal of Experimental Marine Biology and Ecology*, 559, 151836. <https://doi.org/10.1016/j.jembe.2022.151836>
- Turra, A., & Leite, F. (2003). The molding hypothesis: Linking shell use with hermit crab growth, morphology, and Shell-Species Selection. *Marine Ecology Progress Series*, 265, 155–163. <https://doi.org/10.3354/meps265155>
- Turra, A., & Leite, F. P. P. (2004). Shell-size selection by intertidal sympatric hermit crabs. *Marine Biology*, 145, 251–257.
- Turra, Alexander, & Gorman, D. (2014). Subjective resource value and shell abandoning behavior in hermit crabs. *Journal of Experimental Marine Biology and Ecology*, 452, 137–142. <https://doi.org/10.1016/j.jembe.2013.12.018>

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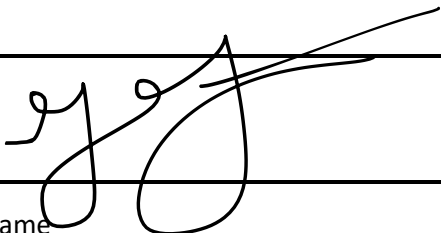
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