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Strawberry Hermit Crab (*Coenobita perlatus*, H. Milne Edwards, 1837) Gastropod Shell Utilization Pattern According to the Type and Size

Y. Jeremy and M. P. Patria[a)]

Department of Biology, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Indonesia, Depok 16424, Indonesia

[a)]Corresponding author: mpatria@sci.ui.ac.id

Abstract. *Coenobita perlatus* is a terrestrial hermit crab belonging to the genus *Coenobita*. Like most other Paguroids, *C. perlatus* utilize empty shells to protect its abdomen. According to research conducted on other species, the preference of each species allows it to assess the suitability of a shell based on its architecture and size, subsequently establishing a consistent sequence of preference among different Gastropod shells. The selection behaviour of *C. perlatus*, however, has never been properly studied and available information regarding its preference is mostly based on observation in the wild. This research aims to investigate the sequence of preference established by *C. perlatus* when assessing the shells of *Turbo setosus*, *Hexaplex cichoreum*, *Hemifusus ternatanus*, with multiple-alternative test, and to determine the degree of relationship between crab morphometric and shell dimensions. The result shows a significant consistency in the sequence of shell selection ($W = 0.5544$), whilst no significant degree of relationship is recorded between any data pair ($R^2 = 0.0031$–0.4146). The different features of the shells significantly affect the crab's fitness; triggering selective behaviour. On the other hand, specific sized shell is often unavailable; forcing crabs to ignore slight difference in size when choosing a shell.

Keywords: Architecture, *Coenobita perlatus*, gastropod, preference, shell size, shell type

INTRODUCTION

The strawberry hermit crab (*Coenobita perlatus* H. Milne Edwards, 1837) is one of several terrestrial hermit crab species, belonging to the genus *Coenobita* Latreille, 1829 [1]. Like other members of the genus, *C. perlatus* has adapted to life on land, and has several morphological, physiological, or behavioural traits that allow them to thrive in terrestrial environment [2]. *C. perlatus* is a common hermit crab species in tropical region of the western Indo-Pacific [3], with populations distributed on various islands [4-11], including the islands of Indonesia [12] and Philippines [13].

Like almost every other member of the superfamily Paguroidea, *C. perlatus* utilize empty Gastropod shells to protect its soft, poorly-calcified abdomen [14, 15], from predators and environmental stresses. According to previous research conducted on other hermit crab species, the pattern of shell utilization by hermit crabs in their natural habitat is influenced the availability of certain shell type in the area and the intrinsic preference of each hermit crab species [16, 17]. This intrinsic preference develops by means of resource partitioning [14, 16], and allows crabs to assess the suitability of a shell based on its architectural design and size [18].

The shell utilization pattern of *C. perlatus*, however, is barely understood and most of the available information regarding its shell preference is based on observation in its natural habitat [16, 19]. This research aims to investigate the sequence of preference established by *C. perlatus* when assessing the shells of *Turbo setosus*, *Hexaplex cichoreum*, *Hemifusus ternatanus*, with multiple-alternative test (procedure first used for analysing shell preference of hermit crab

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by Arce et al. [17]), and to determine the degree of relationship between crab morphometric and shell dimensions. The hypothesis proposed is that *C. perlatus* establishes a consistent sequence of preference towards the three shells and that each morphometric component-shell dimension variable data pair has a different degree of closeness. This research is conducted in hopes that it will give a better understanding of terrestrial hermit crab shell selection behaviour, ecology, and evolution.

EXPERIMENTAL

A minimum of 30 *C. perlatus* individuals were required for the research; all of which were obtained from hermit crab vendors in Jakarta and Bekasi. All of the individuals obtained originated from the island of Lombok, West Nusa Tenggara, Indonesia. Since the hermit crabs were obtained from different vendors, all individuals were acclimated for approximately one week before the observation period. The container used to house the crabs during acclimation process and observation period were cylindrical plastic containers; approximately 19.2 L in volume. Both saltwater and freshwater were provided in two separate bowls that were placed inside the acclimation habitat.

The procedure for the shell type experiment in general, follows the procedure as described by Arce et al. [17], but differs in the number of individuals used and shells provided for each individual. Furthermore, the shell selection by size experiment was not conducted before the shell type experiment, and the size of shells provided in this experiment was not based by the result of shell size experiment. At the start of the experiment, each individual was placed in a plastic container along with ten of each of the three shell types. Each hermit crab was evacuated from their shells prior to being placed inside the container. The apex of the shells was heated in hot water [18]. After 24 hours, shell occupied by the crab was identified and given the numeral rank number one. Each individual was re-evacuated from their shell of choice after all remaining shells of this type were removed from the container. Crabs were then left for another 24 hours to choose one of the remaining two shell types, and the shell occupied after said period was identified and ranked as number two, while the last shell type was ranked as number three, so that a sequence of selection is obtained from each crab. The consistency of sequence of selection between crabs was determined using Kendall's coefficient of concordance which was analysed with Chi-square test, where the null hypothesis was constructed based on no-preference between shell types.

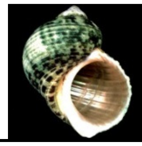
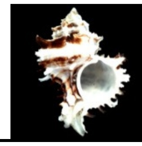
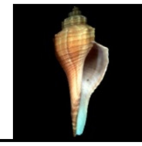
The shell size experiment was conducted after results from the shell type experiment were obtained. Prior the experiment, the cephalothorax shield length, fourth pereopod span, and body mass of each crab was measured. Afterwards, each individual was placed in a container along with ten shells of the same type (i.e. from the same Gastropod species), but with different sizes. The crabs were evacuated from their shells with the same evacuation procedure, prior to being placed inside the container. After 24 hours, the shell occupied by the crab was measured for its length, width, aperture length, aperture width, and mass. The same procedure was repeated for the second and the third shell type. The relationship (i.e. degree of closeness) was determined by the coefficient of determination (R^2) obtained from the power function equation for the 15 data pairs of the three morphometric component and the five shell dimension variables.

RESULTS AND DISCUSSION

The results of the shell type experiment and the shell size experiment are presented in Table 1 and Table 2 respectively. Analysis using Kendall's coefficient of concordance shows that the sequence of shell selection between individuals was significantly consistent ($W_{(2,30)} = 0.5544$; $P < 0.001$), with the sequence being *T. setosus*, *H. cichoreum*, *H. ternatanus* respectively.

On the other hand, none of the crab morphometric component shows a significant relationship with any shell dimension variable; indicated by the relatively low coefficient of determination values as shown in Table 2 ($R_2 < 0.5$). The consistent sequence of shell selection shows that *C. perlatus* established different levels of preference towards the three shell types provided [17]. Evidence suggests that the differences in architectural design of the shells may be the main contributing factor to forming this hierarchic sequence of preference. Turra et. al hypothesized that each shell, with its specific architecture-related characteristics, may act as a unique ecosystem to crabs occupying it [20]. Through evolution and resource partitioning, each hermit crab species may develop a specific preference towards shells with certain morphological traits that gives them the most advantage to facing environmental stresses [16, 17, 20].

TABLE 1. Number of individuals that choose each shell type as first, second, and last choice.

Rank of choice	***Turbo setosus*** 	***Hexaplex cichoreum*** 	***Hemifusus ternatanus*** 	**Total**
1	25	3	2	30
2	5	17	8	30
3	0	10	20	30
Total	30	30	30	

W (Kendall's coefficient of concordance) = 0.554444

χ^2 value = 33.2667; $\chi^2_{(0,001;2)}$ = 13.816

p-value ≈ 0.0000

TABLE 2. R^2 value for each crab morphometric-shell dimension data pair.

	Turbo setosus	***Hexaplex cichoreum***	***Hemifusus ternatanus***
	R^2	R^2	R^2
FPS×SW	0.3773*	0.1951	0.3146
M×SW	0.2853	0.1241	0.4136
CSL×SW	0.2703	0.1995*	0.3223
M×SM	0.2551	0.0221	0.4146*
M×SL	0.2537	0.0074	0.3885
FPS×SM	0.2452	0.0272	0.2968
FPS×SL	0.2426	0.0039	0.2725
FPS×SAW	0.2163	0.1980	0.2158
CSL×SM	0.2019	0.0201	0.3205
CSL×SL	0.1833	0.0031	0.3094
M×SAW	0.1357	0.1340	0.3258
CSL×SAW	0.1061	0.1748	0.2134
FPS×SAL	0.0708	0.0937	0.2183
M×SAL	0.0545	0.0491	0.2691
CSL×SAL	0.0297	0.0870	0.2454

Explanation of abbreviations:
CSL = cephalothorax shield length
FPS = fourth pereopod span
M = mass
SL = shell length
SW = shell width
SAL = shell aperture length
SAW = shell aperture width
SM = shell mass

Asterisks indicate the highest R^2 value that were obtained from the dimensions of each of the shell types

The robust shells of *T. setosus* and *H. cichoreum* have a thick shell wall, ovoid shape, and round aperture [21-23]. According to observation in the wild, stout shells as such is commonly used by burrowing terrestrial hermit crab species, such as *C. perlatus*, and its morphological characteristics may be suitable for coping with environmental stresses faced by said species [19, 24]. The round or D-shaped aperture allows terrestrial hermit crabs to use its larger left chela to fully seal the opening when they retract into the shell; effectively reducing evaporative water loss [24, 25]. The shell of *H. cichoreum*, however, has numerous spine-like ornamentations that may present minor disadvantages to crabs, by affecting mobility and restricting their movements on or under the substrate. Such ornamentation is not present on *T. setosus* shells and may have caused most of the subjects to choose this shell on the first selection round.

As opposed to the other two shells, *H. ternatanus* shell is elongated, thin-walled, and has narrow aperture [26]. According to observation by Szabó, shell with similar morphological traits, such as that of cone shells (*Conus* spp.), conchs (*Strombus* spp.), or cowries (*Cypraea* spp.), are unsuited for Coenobitid occupation, and as a result, are generally avoided by individuals in the wild. Shells with thin walls may not be able to withstand greater impact or friction; rendering hermit crabs occupying it more vulnerable. Crabs are also unable to fully seal the opening of the narrow, elongated aperture; increasing desiccation rate considerably [24]. It is highly probable that these major disadvantages presented by the morphology of such shell is the main reason as to why the majority of individuals used in this research refused the *H. ternatanus* shell till the end of the observation period. On the other hand, the disadvantages presented by the ornamentation of *H. cichoreum* shell may be perceived by the crabs as less significant compared to those presented by the overall shape of *H. ternatanus* shell; hence the crabs tend to choose the former over the latter when more suitable shell that present the least of disadvantages (e.g. *Turbo setosus* shell), is not present.

The result of the shell size experiment shows no significant relationship between *C. perlatus* morphometry and shell dimension; implying that shell size does not influence shell selection by hermit crab. However, based on the R^2 values obtained, it is shown that the crab morphometric has a stronger relationship with the dimensions of *H. ternatanus* shell when compared with the other two shells. Mantelatto et. al proposed similar finding based on a laboratory experiment using *Pagurus exilis* individuals from Argentina, which demonstrated no particular preference among the shell dimensions studied but shows a stronger relationship with *Buccinanops gradatum* shell dimensions; despite it being less preferred according to the shell type experiment [18]. Although the result obtained seemingly contradicts previous knowledge regarding the need to switch to a larger shell as hermit crabs increase in size [27-29], this phenomenon can be explained by considering the biology and evolution of hermit crabs.

Unique morphology of each shell type allows it to act as different environments for hermit crabs [20], and crabs that utilize shells with suitable morphology tend to have higher survival chance than those that utilize shells with unsuitable morphology [17]. In this case, the ability to distinguish different shells and choose the appropriate one is a preferred trait in the selection mechanism. On the other hand, the limited availability of shells with specific size in the wild and the high dependency of hermit crabs on shells [27, 30], often force individuals to utilize shells that are not of appropriate size. In this case, the flexibility in using shells of different sizes is the preferred trait in the selection mechanism. Such information may explain why crab morphometric shows stronger relationship with *H. ternatanus* shell dimensions, despite it being generally avoided when other shells are present. Individuals tend to choose shells with suitable morphology (e.g. *T. setosus* shell) even when it is not exactly of appropriate sizes; hence the R^2 values became low. On contrary, crabs will only choose unsuitable-shaped shell if the size is appropriate enough, since shells with inappropriate size will reduce their overall fitness greatly; hence the R^2 values became high.

The research results suggest that the influence of shell type (i.e. morphological traits of a shell unique to the species it originated from) on shell selection by *C. perlatus* is more significant than shell size. This statement is further supported by result of previous observation that hermit crabs will only move to a larger shell if their body size increases markedly and not every molting process (i.e. increments of body size) is followed by shell exchange [1]. This implies that the range of shell size that is considered suitable by hermit crabs may be relatively wide, as opposed to being specific, and that crabs of different sizes can occupy shells of the same size. The shells used in this experiment may not vary significantly in size; thus, resulting in subjects ignoring slight differences in shell size.

CONCLUSION

C. perlatus establishes a hierarchic sequence of preference among the three shell types provided, with the decreasing sequence of preference being *T. setosus*, *H. cichoreum*, *H. ternatanus*. The result is consistent with previous observations regarding shell types which are often used by individuals in natural habitat and shows that advantages or disadvantages presented by certain morphological traits can influence the shell preference of hermit crabs. On the other hand, although different morphometric components show varying degree of relationship with the various dimension variables studied and the data pair with the strongest relationship can be determined, none of the R^2 value obtained shows significant degree of relationship. This is most likely due the shells used in this experiment not varying significantly in size.

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