ISSN 2321–340X

Journal of Aquatic Biology & Fisheries | Vol. 6 | 2018 | pp. 165-175

SHELL SELECTION AND UTILIZATION BY THE TERRESTRIAL HERMIT CRAB *COENOBITA RUGOSUS* IN NATURAL AND LABORATORY CONDITIONS

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Abstract: Extensively distributed along tropics and subtropics, terrestrial hermit crabs play critical roles in coastal ecology and they often show preferences towards few gastropod shells in natural ecosystems. The nature of selection of empty gastropod shells as protective 'home' from natural environment for shelter varies with species. In this study the vacant shell search and selection by the terrestrial hermit crab *Coenobita rugosus* (Coenobitidae; Crustacea) was found to be governed by various parameters including the presence of vacant shells in vicinity, types of vacant shells, and morphometric characters of shells. Laboratory simulation for 72 hours of exposure of hermit crab to different types of vacant host shell combinations followed by statistical evaluation revealed specific relationship in shell selection by hermit crab with morphometric characteristics of vacanthost shells.They also exhibit a greater plasticity in shell selection.

Key words: Coenobitidae, Utilization, Shell use patterns, Gastropoda, Morphometry, Host shell, Kerala.

INTRODUCTION

Hermit crabs naturally select diverse varieties of vacant molluscan shells, particularly gastropod shells,which makes shell a major limiting resource for their survival (Ohmori *et al*., 1995; Barnes, 1999; Mantelatto and Garcia, 2000; Meireles *et al*., 2008; Laidre and Trinh, 2014). Shell utilization process by hermit crabs are determined by shell dimensions. Shell utilization pattern vary between hermit crabs and are greatly influenced by the available shell's size, type, shell preferences and also by area of occurrence of hermit crab (Mantelatto and Garcia, 2000; Meireles *et al*., 2003; Mantelatto and Meireles, 2004).

Coenobita, an ecologically valuable terrestrial hermit crab genus, represented by sixteen species inhabits tropical and subtropical regions of the world (Mclaughlin *et al*., 2007, 2010). *Coenobita rugosus* is a semi-terrestrial species recorded from the coastal region of Kerala (Reshmi and Biju Kumar, 2010). They occupy a great variety of shells, though the preference is for shells lacking columella (Ball, 1972). A well-fitting shell is essential for semi terrestrial hermit crab for preventing evaporation and to carry ample water (Sallam *et al*., 2008). Appropriate shell size is needed for invading into inlands which allows shade, food and freshwater to semi-terrestrial hermit crab. When compared to marine species, terrestrial hermit crabs have no intense competition for shells (Sallam *et al*., 2008). Marine hermit crabs tend to be very particular about the shells they occupy (Pechenik *et al*., 2015). All these depend on the shell investigation and acquisition behaviours in hermit crabs (Hazlett, 1981; Elwood and Neil, 1992), which is a lengthy process. Here the assessment is done by comparing the resource value of shell already occupied with the encountered shells (Gherardi, 2005; Tricarico and Gherardi, 2007). Many studies have been done to understand the differential shell species selection (e.g., Laidre and Vermeij, 2012) and specific shell preference (Abrams, 1978; Bertness, 1981a) of hermit crabs. Hermit crabs acquire used shells by frequent exchange of shells with one another (Laidre, 2010).

The studies on shell utilization by land hermit crabs has been done in several areas of the world,including Western Atlantic by Morrison and Spiller (2006); Eastern Pacific by Abram (1978), Guillen and Osorno (1993) and Laidre and Vermeij(2012); North Pacific by Willason and Page (1983) and Szabo (2012); Western Pacific by Boneka *et al*. (1995); Red Sea by Volker (1967), Sallam *et al*. (2008) and Sallam (2012); Persian Gulf by Seyfabadi *et al*. (2013), Western Indian Ocean by Barnes (1999, 2001, 2002). Few works have been carried out in India on the shell selection in natural condition (Khan and Natarajan, 1982; Trivedi *et al.*, 2013, Trivedi and Vachhrajani, 2014) but no serious works have been conducted in laboratory conditions.This paper explains the shell use by land hermit crab *Coenobita rugosus* inhabiting west coast of India in natural and experimental conditions.

MATERIALS AND METHODS

Collection and preparation

Terrestrial hermit crab *Coenobita rugosus* found commonly along the coastal region of Kerala coast of India was the experimental animal, and this species is not included in any schedules of Wildlife (Protection) Act of India and in the red list of endangered species. Specimens for live experimental study were collected from the intertidal areas of Thirumullavaram beach (08^{0}53' 32.5" N; 76^0 33' 18.4" E), Kollam District, Kerala, India and transported to the wet laboratory, where it was acclimatized and reared in glass tanks.

Host shell morphometric characters like Shell Length (ShL), Shell Width (ShW), Aperture Length (AL), Aperture Width (AW), Shell Weight (Wt), Internal Volume (IV), External Volume (EV) and Aperture Perimeter (AP) were recorded to the nearest millimeter using a digital Verniercalliper. Hermit crab measurements like Shield Length (SL), Carapace Length (CL), Thoracic Length (TL), Abdominal Length (AL), Width (W) and weight were also recorded.

Experimental setup

Three experimental set-ups were used to study shell utilization and preference in hermit crabs. The experiments were conducted in 5 glass tanks of 2 feet (60 cm) length and one feet (30 cm) breadth and height. These tanks were filled with sand up to 6 cm. In each tank 10 species of gastropod shells were introduced; the gastropod shells selected for the study is given in Table 1. Morphometric characters of shells and hermit crabs were measured using digital calipers. Weight of each shell and hermit crabs selected was noted individually using electronic balance. Internal volume of the shell was taken by filling it with sand till the aperture and by weighing it, in an electronic balance. External volume of the shell was measured by water displacement method. Shell selection behaviour by hermit crabs was noted.

Experiment I

In this experiment, five animals of same size group hermit crabs with natural host shell were introduced in each tank with ten equal combinations of shells. The morphometric measurements of the hermit crabs and the host shells were recorded prior to the experiment. The experiment was carried out for 72 hours. The experimental set-up was kept undisturbed and observed for shell selection. The time taken for the selection of a new host shell and the shell species selected by each crab was recorded separately.

Experiment II

Second set of experiments were carried out with naked hermit crabs. For this the hermit crabs were forced to come out of their host shell by gentle heating the apex of the shell. Then they were kept in five different tanks containing equal combinations of 10 shell species. The morphometric measurements of the hermit crabs and host shells were recorded prior to the experiment. The time taken by the hermit crab for shell selection and the species selected by them were recorded for 72 hours.

Table 1. List of gastropod shells used for the laboratory experiments on shell selection by the hermit crab *Coenobita rugosus*

Sl.No.	Species	Family
1	*Tanea lineata* (Roding,1798)	Naticidae
2	*Natica vitellus* (Linnaeus,1758)	Naticidae
3	*Ficus variegata* (Roding ,1798)	Ficidae
4	*Tibia curta* (Sowerby I, 1843)	Strombidae
5	*Semicassis faurotis* (Jousseaume,1888)	Cassidae
6	*Purpura bufo* (Lamarck, 1822)	Muricidae
7	*Murex tribulus* (Linnaeus, 1758)	Muricidae
8	*Bufonaria echinata* (Link, 1807)	Bursidae
9	*Bufonaria crumena (*Lamarck, 1816)	Bursidae
10	*Babylonia zeylanica* (Brugier, 1789)	Buccinidae

Experiment III

In this experiment, one hermit crab each was kept in five tanks with different shell combinations. Like other experiments the experimental animal and host shell species were identified and measured for necessary morphometric characters prior to the experiment. Duration of the experiment was 72 hours. Time taken for the shell selection and shell species selected were noted.

Statistical Analysis

The morphometric parameters of the gastropod shells in the experiments were compared by Analysis of Variance (One Way ANOVA). Multivariate correlation analysis was performed to determine the relationship between morphometric characteristics of hermit crabs and their preferred shells. Shell-size preference was analyzed using multiple linear regression $ln\ Y = a + b\ lnX$, where Y = shell measurements and X = hermit crab measurements after natural logarithm transformations. The regression and correlation coefficients were used to elucidate morphometric relationships. Principal Component Analysis (PCA) with factor loadings based on Eigen values were employedto find out the morphometric factors that influence the shell selection by the hermit crabs. For all statistical evaluations a two-tailed probability value <0.05 was considered significant (Zar, 1996). Different statistical analyses were performed using R software.

RESULTS

Shell selection in natural condition

The results of the regression analysis showing morphometric relationships of *Coenobitarugosus* and their host gastropod shells are given in Table 2. Host shell width, aperture length and aperture width showed strong relationship with the hermit crab morphometry. These crabs occupied a great variety of shells, but the most abundantly used shell species from the random collections were recorded and used for further experiments.

Shell selection in experimental conditions

The results of the laboratory experimental studies are presented in four parts: (i) Shell investigation and shell selection behaviour; (ii) Shell selection when the animal was with shell; (iii) Shell selection when the animal was without host shell and (iv)Shell selection in *Coenobita rugosus* when kept with different shell combinations.

Shell investigation

In the experiment of shell selection by hermit crabs with shell, hermit crabs choose suitable shells after a lengthy process of shell investigation (Fig. 1). This is to assess the size and quality of the new shelter before exchanging. The assessment is done by comparing the resource value of shell already occupied with the encountered shells. During the process of shell investigation the crab grasps the shell with its walking legs and chelipeds and investigates the outer surface of shell by moving its chelipeds and it rotates the shell to bring the aperture to upper position and begins to investigate the interior by inserting one or both chelipeds and sometimes one or two walking legs. By this the hermit crab gets detailed information about the size, internal volume, shape, weight and quality of the new shell relative to that of currently occupied shells. After investigation the crab moves from the original shell to the new one. The crab now may investigate the original shell it occupied and may move back to it if it finds it to be better than the new one.

Shell selection when the animal was with shell selected from natural environment: The animal with the host shell species showed a different selection pattern. The hermit crab naturally occupied in the shell of *Natica vitellus* possessed the same shell throughout the experiment. Those occupied in the shell of *Turbo intercostalis* in the natural environment showed preference towards the shells of *Natica vitellus***,** *Babylonia zeylanica* and *Purpura bufo*. The animals found naturally in *Babylonia zeylanica* moved to *Purpura bufo,* showing their preference towards shells with more thickness.

Correlation analysis (Table 3) comparing the morphometry of hermit crab and host shells showed strong correlation between the following parameters: shell length × volume of hermit, shell width × abdominal length, shell weight × abdominal length, aperture length × abdominal length, aperture length × volume of hermit, aperture width × abdominal length, aperture width × weight of hermit crab, aperture width × carapace width, aperture perimeter × abdominal length and internal volume × abdominal length. External volume of shells also showed

Table 2. Regression analysis showing morphometric relationship between *Coenobita rugosus* and their most preferred host gastropod shells collected from natural condition

Host shell species	Relation	Linear equation	R^2 value
	Sh.L x SL	ln Sh.L = -1.84 + 0.32 lnSL	0.838**
	Sh.L x SW	ln Sh.L = -1.50 + 0.38 lnSW	0.881**
Euchelus asper	Sh.W x SL	ln Sh.W = -0.30 + 0.32 lnSL	0.849**
(n = 26)	Sh.W x SW	ln Sh.W = 1.24 + 0.36 ln SW	0.826**
	AL x SL	ln AL = -0.43 + 0.48 ln SL	0.776**
	AL x SW	ln AL = 1.55 + 0.68 ln SW	0.767**
	AW x SL	ln AW = -1.04 + 0.66 ln SL	0.840**
	AW x SW	ln AW = 1.55 + 0.68 ln SW	0.767**

** P < 0.01

Fig. 1(a-t). Various stages of shell investigation processes shown by *Coenobita rugosus*

Table 3. Multivariate correlation analysis between hermit crab and host shell morphometry in experiment conducted on *Coenobita rugosus* with host shell

Parameter	HC: SL	HC: AL	HC: CW	HC: Wt	HC: V	HS: L	HS: W	HS: AL	HS: AW	HS: AP	HS: Wt	HS: IV	HS: EV
HC: Shield Length	1												
HC: Abdominal Length	0.053	1											
HC: Carapace Width	0.645**	-0.191	1										
HC: Weight	0.709**	-0.361	0.968**	1									
HC: Volume	0.803**	-0.232	0.296	0.482	1								
HS: Length	-0.025	-0.318	-0.181	-0.022	0.186	1							
HS: Width	-0.139	0.357	-0.268	-0.253	-0.142	-0.287	1						
HS: Aperture Length	-0.028	0.254	-0.146	-0.157	0.034	-0.014	0.613*	1					
HS: Aperture Width	0.049	0.193	0.254	0.181	-0.097	-0.401	0.594*	0.264	1				
HS: Aperture Perimeter	-0.031	0.046	-0.063	-0.002	-0.048	-0.049	0.843**	0.481	0.569*	1			
HS: Weight	-0.282	0.105	-0.102	-0.139	-0.289	0.509*	0.292	0.404	0.122	0.436	1		
HS: Internal Volume	-0.223	0.197	-0.297	-0.319	-0.146	-0.153	0.925**	0.657**	0.510*	0.809**	0.334	1	
HS: External Volume	-0.046	-0.375	0.012	0.079	0.074	0.638*	-0.204	-0.256	-0.24	-0.049	0.388	-0.203	1

(** P<0.01; * P<0.05; HC: Hermit Crab Morphometry; HS: Host Shell Morphometry)

Table 4. Principal Component Analysis of transformed morphometric variables of host shell of the terrestrial hermit crab *Coenobita rugosus*

Host Shell Morphometry	Component		
	1	2	3
Length	-0.254	0.879	-0.116
Width	0.952	-0.023	0.061
Aperture Length	0.718	0.142	-0.588
Aperture Width	0.688	-0.251	0.495
Aperture Perimeter	0.879	0.193	0.21
Weight	0.392	0.782	-0.051
Internal Volume	0.932	0.061	-0.063
External Volume	-0.278	0.779	0.404
Eigen value	3.851	2.117	0.821
% of variance	47.89	26.468	10.265
Cumulative % of variance	47.89	74.358	84.623

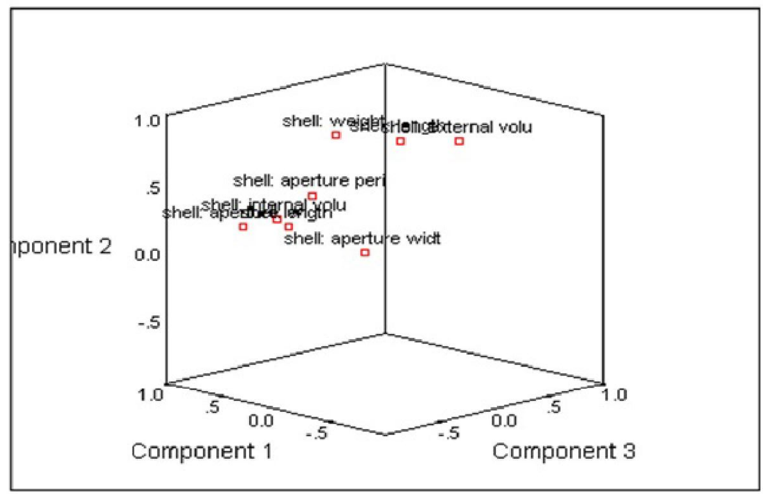

Fig. 2. Factor loading component plot of principal component analysis of host gastropod shell parameters determining shell selection in *Coenobita rugosus* with shell.

relationships with hermit crab carapace length, weight and volume.

Even though several morphometric variables of hermit crab registered significant relationship with host vacant shell structure variables, few parameters had significant selection role which was elucidated using Principal Component Analysis (PCA). Shell selection in hermit crab *Coenobita rugosus* showed that several parameters influence the selection process (Table 4; Fig. 2). The principal component 1 (PC1) was width of the shell, followed by internal volume (47.89% of variance). Length and weight of the shell showed the high factor loading in Principal component 2 (PC2) with 26.47% of the variance. Principal component 3 (PC3) showed 10.27% of the variance, with shell aperture width and external volume.

Shell selection when the animal was without host shell

When the naked hermit crab was introduced into the experimental tanks with the ten selected species of shell, they avoided investigation and randomly selected the first encountered shell. In this experiment hermits selected *Tanea lineata, Natica vitellus, Ficus varieagata, Semicassis faurotis, Purpura bufo, Bufonaria crumena, Babylonia zeylanica,* and *Murex tribulus.* Further shell selection was noticed in hermit crabs occupying the shells of *Semicassis faurotis* and *Murex tribulus* were the hermit later moved to *Tanea lineata.* There was a random selection of shells in this case.

Results of correlation analysis of experiment conducted on *Coenobita rugosus* without host shell is shown in Table 5. Regression analysis conducted showed that external volume of shell was an important factor influencing the hermit crab depending on weight and volume of the crab. All the other parameter showed a value more or less close to zero and had a balanced effect.

Principal component analysis, used to elucidate the factors contributing to shell selection in hermit crab *Coenobita rugosus* showed that several morphometric parameters play an important role in the process (Table 6; Fig. 3) The principal component 1 (PC1) was aperture perimeter, followed by aperture length with 35.597% of variance. Principal component 2 (PC2) described 21.892% of the variance, with width most highly correlated with PC2. Aperture width was the shell parameter associated with PC3, which accounted for 13.289% of variance.

Shell selection in *Coenobita rugosus* with different shell combinations: The shell selection in *Coenobita rugosus* was also studied by keeping the animal with different shell combinations in the laboratory condition. When the animal was presented with different shell combinations it showed no sign of selection for 48hrs after which selection occurred. As the hermit crab was presented in each tank with its host shell it didn't show any random selection. In each tank shell selection was observed with the crab selecting the most appropriate one as its home. In all cases the hermit crab choose shells that were slightly larger than the existing host shells except in one case were the animal was inhabiting a much larger shell moved back to a shell of more suitable size. In 2-3 cases, the crab after selecting a new shell showed a tendency to re-enter the host shell within hours. This may be due to the less suitable size, shape or damage of the newly selected shells. Shell preference could be clearly seen in this situation.

DISCUSSION

In nature, *Coenobita rugosus* was largely collected from the shells of *Euchelus asper.* The study showed positive correlations between morphometry of hermit crab and shell morphometry in regression analysis (Table 2). Parameters of *Coenobita rugosus* (shield length and shield width) showed a positive correlation to all shell parameters shell length, shell width, aperture length and aperture width) of *Euchelus asper.* From the study it is clear that morphometry of shells plays a significant role in its selection by the host hermit crabs. According to Sallam *et al.* (2008) shell dimensions are the main determinant of shell utilization in hermit crabs.

The morphometric characters of hermit crabs and the shells associated with it have morphometric relation and were independent of shell species (Mantellato *et al.*, 2007). According to Meireles *et al.* (2008) the morphometric relationships between shell aperture length and hermit crab shield length best describes the association between hermit crab and selected shells. It is clear thatthe size of aperture

Table 5. Correlation analysis of experiment conducted on *Coenobita rugosus* without host shell.

Parameter	HC: SL	HC: AL	HC: CW	HC: Wt	HC: V	HS: L	HS: W	HS: AL	HS: AW	HS: AP	HS: Wt	HS: IV	HS: EV
HC: Shield Length	1												
HC: Abdominal Length	0.053	1											
HC: Carapace Width	0.645**	-0.191	1										
HC: Weight	0.862**	-0.158	0.746**	1									
HC: Volume	0.803**	-0.23	0.296	0.823**	1								
HS: Length	0.019	-0.001	0.103	0.091	0.011	1							
HS: Width	-0.182	-0.023	-0.103	-0.029	-0.045	0.01	1						
HS: Aperture Length	-0.072	0.035	0.002	-0.004	-0.056	0.776**	0.146	1					
HS: Aperture Width	-0.102	0.121	0.048	-0.081	-0.197	-0.036	0.249	0.065	1				
HS: Aperture Perimeter	-0.109	-0.068	-0.009	-0.011	-0.046	0.634**	0.232	0.704**	0.373*	1			
HS: Weight	-0.027	-0.083	0.115	0.103	0.007	0.198	0.536**	0.151	0.106	0.372*	1		
HS: Internal Volume	-0.139	-0.091	-0.029	-0.106	-0.124	0.048	0.347*	0.068	0.087	0.287	0.492**	1	
HS: External Volume	0.106	-0.035	0.017	0.267	0.285	0.089	0.193	0.014	0.068	0.018	0.318	0.09	1

(----** P < 0.01; * P < 0.05; HC: Hermit Crab Morphometry; HS: Host Shell Morphometry).

Table 6. Principal Component Analysis of transformed morphometric variables of host shell of the terrestrial hermit crab *Coenobita rugosus* without shell.

Host Shell Morphometry	Component 1	Component 2	Component 3
Length	0.696	-0.578	-0.241
Width	0.516	**0.579**	0.089
Aperture Length	0.744	-0.552	-0.057
Aperture Width	0.323	0.208	**0.821**
Aperture Perimeter	**0.858**	-0.261	0.234
Weight	0.645	0.533	-0.24
Internal Volume	0.474	0.498	-0.076
External Volume	0.248	0.368	-0.449
Eigen value	2.848	1.751	1.063
% of variance	35.597	21.892	13.289
Cumulative % of variance	35.597	57.488	70.778

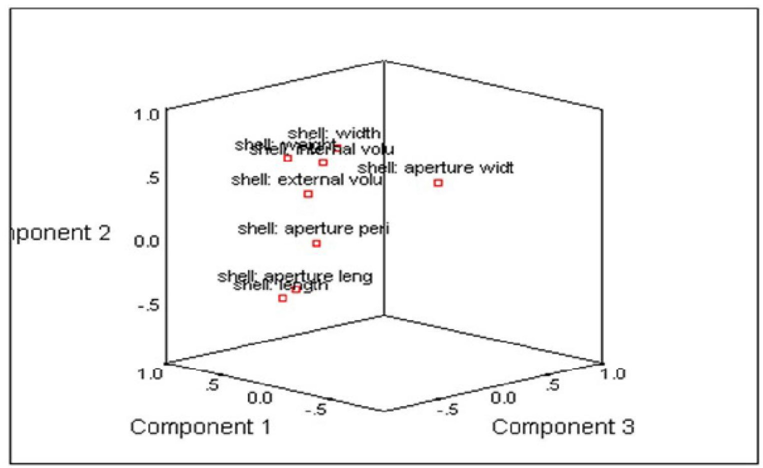

Fig. 3. Factor loading component plot of principal component analysis of host gastropod shell parameters determining shell selection in *Coenobita rugosus* without shell.

had a great influence on the hermit crab shell selection. There is a close relationship between the shell use and availability of resources (Volker, 1967). Shell utilization pattern vary between hermit crab and are greatly influenced by the available shell's size and type, hermit crabs shell preferences and also by area of occurrence of hermit crab (Garcia and Mantelatto, 2000; Mantelatto and Garcia, 2000; Meireles *et al*., 2003; Mantelatto and Meireles, 2004). A great variety of shells are found occupying by the hermit crabs and this indicates resource partitioning between hermit crabs. This may be due to difference in body size, reproductive behaviour etc (Imazu and Asakura, 1994). Great diversity of shells occupied by a species in nature depends on availability of different shell species and relative abundance of the gastropods and their mortality rate in an area (Meireles *et al*., 2003) and also abiotic conditions of the area also determine the abundance of invertebrate species.

Shell investigation and shell selection behaviour

Shell investigation gives detailed information about the size, internal volume, shape, weight and quality of the new shell relative to that of currently occupied shells. This is an important process in nature by which the crab chooses a home wisely.

Shell selection when the animal was with shell selected from natural environment: Regression analysis comparing the morphometry of hermit crab and host shells showed positive correlation between the different parameters. This shows that the carapace width, abdominal length, weight and volume of hermit crab directly depended on the shell characters like length, width, weight, aperture length, aperture width, aperture perimeter, internal volume and external volume. Analysis showed that shell utilization process in hermit crab was determined by shell dimensions.

Shell selection when the animal was without host shell

In naked hermit crab the first shell selection was random and not based on shell species or detailed shell characteristics. This showed that in such a situation the hermit crab gave preference for protecting their vulnerable abdomen first and later on with time they selected shells suitable in all parameters for them.

Live experiments conducted proved that hermit crabs in the laboratory conditions choose shells that are most occupied in the field. This observation is in agreement with the results of Abrams (1978), Siu and Lee (1992), Ohmori *et al*. (1995), Hahn (1998), Dominciano and Mantelatto (2004), Meireles and Mantelatto (2005), Biagi *et al*. (2006) and Mantelatto *et al*. (2007). There are also many studies that supported the absence of shell selection preference under laboratory conditions (Siu and Lee, 1992; Garcia and Mantelatto, 2001; Mantelatto*et al*., 2005). Shell investigation and acquisition behaviours in hermit crabs (Hazlett, 1981; Elwood and Neil, 1992) is a lengthy and complicated process were the hermit crabs ''investigate'' vacant shells by examining the shell exterior using their antennae, chelipeds, and walking legs and by inserting their chelipeds into the shell aperture. It is influenced by the presence of other shells, hermits, stones etc. (Elwood and Neil, 1992; Brown *et al.*, 1993). ''Shell switching'' takes place when the crab holds the new shell with the aperture facing upward and releasing its abdominal grip on the old shell, rapidly swings its abdomen over to occupy the new shell. Solitary crabs often retain hold of their original shell and ''reversals'' occur when a crab moves back and forth between shells before finally choosing one (Rotjan *et al.*, 2010). The assessment is done by comparing the resource value of shell already occupied with the encountered shells (Tricarico and Gherardi, 2007; Gherardi, 2005). Hermit crabs show preference to lighter shells (Herreid and Full, 1986) when compared to heavy shell which otherwise adversely affect the reproduction and growth of hermit crabs (Elwood *et al*., 1995; Osorno *et al*., 2005). The length of solitary shell investigations by hermit crabs was highly variable, ranging from 3 to 429 seconds (Rotjan *et al.,* 2010).

Present study showed that when the hermit crab was introduced into the tank with other gastropod shells, they preferred shells with larger aperture width and thicker shells like that of *Natica vitellus, Turbo intercostalis, Babylonia zeylanica* and *Purpura bufo*. At the same time, when they were exposed to the shells naked, the choice was random, as they chose a variety of shells irrespective of such shell characters. In natural habitat it is found to occupy wide varieties of shells like *Thias rudolphi, Thias bufo, Babylonia zeylanica, Babylonia spirata, Nerita albicilla, Turbo brunneus, Nerita polita, Euchelus tricarinata* and *Euchelus asper* (Reshmi and Biju Kumar, 2010). Comparing the results of shell selection in natural and laboratory condition in *Coenobita rugosus* showed that morphometric parameters of the shells had a major role in shell selection process in hermit crabs. Regression analysis conducted in both cases showed positive correlation between parameters of hermit crab and shells selected in natural and laboratory conditions. This shows that the hermit crab choose a wide variety of shells for protection, when more diversity of gastropod shells are available and thus shells forms the major limiting factor or resource for their survival (Ohmori *et al*., 1995; Barnes, 1999; Mantelatto and Garcia, 2000; Meireles *et al.*, 2003; Mantelatto and Meireles, 2004).

According to Yoshino (1999), less preferred shell species are actively chosen when more preferred shell species in the field are of less suitable size. Shells with larger internal volume are preferred by hermit crabs that face desiccation and thermal stress (Bertness, 1981b; Taylor, 1981) and this may be due to the fact that larger internal volume would reduce the direct contact of the animal body with the outer environment. According to sallam *et al*. (2012) shell dimesions are the determinants for shell utilization in *C. Scaevola* in Red Sea. *Coenobita rugosus* occupied more variety of shells under favourable conditions, all of which were relatively thicker and without a cloumella. A similar observation has been made by Ball (1972) and Kinosita and Okajima (1968) on shells *Coenobita* sp. The high number of occupied shell species in the experimental study indicated that, for the studied population, occupation is influenced by the shell availability.

Experiments conducted with hermit crabs and different shell combinations provided data supporting the shell selection process depending on shell characters and also on the presence of other shell depending species of invertebrates. Majority of hermit crabs choose shells with larger internal volume and aperture width when compared to other shell features and this helps to reduce desiccation, thermal stress and enhances resistance for inter-tidal species.

CONCLUSION

From the above shell selection studies it can be concluded that the shell selection in the semi-terrestrial hermit crab, *Coenobita rugosus* is influenced by the host shell features such as weight, aperture width, aperture perimeter, internal volume and length. Though this species favours certain species of shells, it exhibits a greater plasticity in shell selection. In general, hermit crabs always select optimal shells based on shell characters like shell length, shell width, aperture length, aperture width and aperture perimeter in addition to certain other characters like shell type, weight, internal volume, shell availability, shell quality and shell experience. Hermit crabs are good ‘ecosystem engineers’ as they help in distribution of diverse variety of invertebrates through use of gastropod shells. They can be used as a key indicator species because its rarity or abundance on any shore reflects the degree of healthiness of that shore.

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