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The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.03
TPI 2019; 8(3): 22-30

www.thepharmajournal.com
Received: 11-01-2019
Accepted: 15-02-2019

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First report on the use of gastropod shells by hermit crabs from the eastern coast, India

Samir Sardar, Debojyoty Ghosh, Pradipta Kumar Ghosh, Koustav Bhattacharjee and Koushik Pal

Abstract
The assemblage of different crab species in the shoreline ecotone region are potential indicators for maintaining structural and functional integrity of the coastal ecosystem. The hermit crabs among the different crab species of this habitat is notable for understanding the intrinsic relationship of the crab dependence on gastropod shells which is important to explain the shell use pattern in nature. Random sampling of specimens was done from the intertidal zone of extended mud flats of Bakkhali and Frazerganj of Indian Sundarban for a period of one year, which showed greater availability of one type of gastropod shell *Telescopium telescopium*. Twenty one different types of gastropod shells were chosen by *Clibnarius infraspinatus and Clibnarius padavensis* as their microhabitat, among which later shows greater affinity for *Telescopium* shells. The statistical analysis showed that the crab weight and shell weight are positively correlated at a significant level ($p< 0.01$). Present communication also suggests preference of microhabitat selection by hermit crabs depends on various factors like, spatial distribution and availability of resources, durability of the shells, inner columellar space, coiling of shells and association of epibiotic covering of the shells (scallops and barnacles).

Keywords: Ecotone, gastropod shells, Indian Sundarban, microhabitat selection

1. Introduction

Sandy beaches are the dynamic environment within which invertebrate crab diversity are maximum. Among all the crab species, the anomuran hermit crab is special for their morphology and complex behavior of shell choice. Hermit crabs actively transport, recycle, and concentrate gastropod shells in this zone (Thompson *et al.*, 1985) [1]. After metamorphosis they opt for empty molluscan shells as their temporary refuge (microhabitat) for protecting their soft vulnerable abdomen from erosion and predation (Vance, 1972; Angel, 2000) [2, 3], desiccation (Taylor, 1981; Brodie, 1999) [4, 5] and osmotic stress (Shumway, 1978) [6]. A pioneer work on hermit crab shell selection behaviour started by Thompson (1910) [7] and continued till present time are indicative of the enormous importance of hermit crabs shell selection behavior which varies with different habitats, acting in different ways on each crab species (Bertness, 1981) [8], in different areas (Garcia & Mantelatto, 2000) [9]. The empty molluscan shells chosen are from gastropods (Reese, 1963; Hazlett and Provenzano, 1965; Harvey and Colasurdo, 1993; Brodie, 1999) [10, 11, 12, 5] and this selection in the natural habitat depends on various factors like availability of molluscan shells (Bollay, 1964; Reese, 1962; Vance, 1972a; Bach, Hazlett and Rittschof, 1976 and Kellog, 1976; Conover, 1978; Bertness, 1982; Pinheiro *et al.*, 1993; Floeter *et al.*, 2000; Turra and Leite, 2001; Sant'Anna *et al*., 2006) [13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23], predator presence (Rotjan *et al.*, 2004) [24], hydrodynamics (Hahn, 1998) [25], dilution of sea water (Davenport *et al.,* 1980) [26], chemical cues (Mesce, 1982; Benoit *et al*., 1997) [27, 28] abrasion and extremes of temperature (Reese, 1969; Vance, 1972) [29, 2].

In addition to these factors choices on specificity for shell types (Reese, 1962; Hazlett, 1978; Abrams 1978; Conover, 1978; Elwood, Mc. Clean and Webb, 1979; Bertness, 1980) [14, 30, 31, 18, 32, 33], crab growth rate (Wada *et al*., 1997) [34]; shell use history (Elwood *et al.*, 1979; Turra and Leite, 2003) [32, 35] and environmental threats (Bulinski, 2007) [36] also makes the pattern of shell selection a much more complicated process to understand this system. Shell species-preference appears to be related to the angle of the columella of the shell with the substratum (ground) and the posture of the crab whilst inhabiting the shell was studied by Dowds and Elwood (1982) [37]. Fewer studies have investigated discrimination of gastropod shells based on shell condition (Conover 1978; McClintock 1985; Wilber 1989; 1990) [18, 38, 39, 40].

In this case of shell discrimination, hermit crabs use their tactile cues to judge between intact shell and drilled shell (Pechenik and Lewis 2000) [41]. A close intricate relationship exists between hermit crabs and its'chosen gastropod shells which directly influence the life history stages of the hermit crabs and its' survivality. Hence studying this microhabitat selection pattern is very important to understand the close knit ecology of this crab species.

Majority of the studies on hermit crab abundance and shell use/ choice was made on the western coast of India. Unfortunately, no such study was done from the eastern coast of India. So an attempt was made to study the species abundance of hermit crabs and their shell utilization pattern from a small coastal region of Sundarban Biosphere Reserve, South 24 Parganas (West Bengal, India) where the beach is enormously exposed during extreme low tide, facilitating a rich foraging ground for the hermit crabs.

2. Materials and Methods

2.1 Study Area

The field study on hermit crabs and its'sampling for specimen collection was done on the extended beaches of Bakkhali and Fraserganj of Namkhana island located in the district of South 24 Parganas, West Bengal, India with latitude $21^{0}34^{/}$ N and longitude $88^{0}15^{/}$ E. The sampling area of the intertidal zone of the beach (Fig 1) covers a minimum width of about 90 meters (Fraserganj area) to a varying width of 180- 240 mt. towards the estuary (Bakkhali mohona). The beach was extended nearly 1 km towards Fraserganj and 2 km towards estuary from the entry point of Bakkhali beach during extreme low tide.

Fig 1: Map of the study area.

2.2 Methodology

The present work was conducted from January 2017 to December 2017 (irrespective of seasons and months) during which different types of gatropod shells irrespective of size and weight inhabited with hermit crabs (considered as chosen) and those shells which do not inhabit hermit crabs (considered as unchosen) were randomly handpicked from the natural habitat of the intertidal zone of the sea shore. Specimen collection was effective only at the time when the beach was extensively exposed during low tide. After the collection of samples, gastropod shells both (chosen and unchosen) were stored within big plastic jars containing 4% formaldehyde (HCHO) solution for laboratory analysis and identifications.

Analysis on morphometry of both crabs and shells (Fig. 2) were done with the help of slide calipers and respective weights were taken by the help of electronic weigh balance (Keory 300). Taxonomic identification of gastropod shells was done following the classification of Vaught (1989) [42] as documented in Catalogue of marine mollusks- polyplacophora and gastropoda (Dey2016) [43]. Further taxonomic identification of hermit crabs upto the possible lower taxonomic category was done following the classification scheme of Ajmal Khan and Natarajan, R. (1984) [44] and by the help of scientists of Zoological Survey of India (ZSI), Kolkata. The durability of different types of gastropod shells was also tested in the laboratory by acid digestion in 3(N) Hydrochloric acid (HCl) at room temperature to determine the durability of the molluscan shells and two-tailed single t-test was performed to analyze the result.

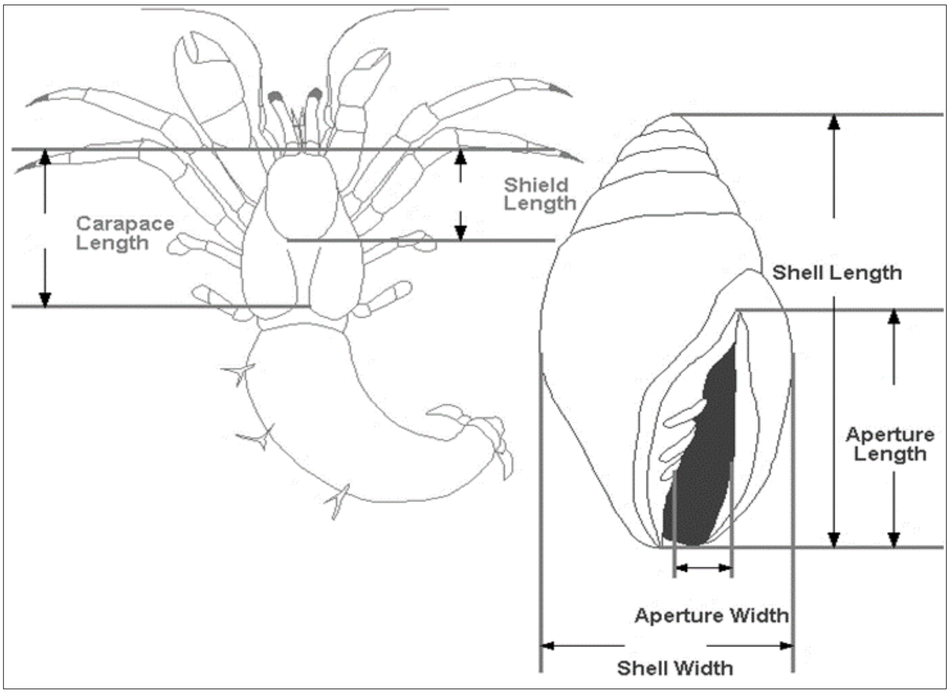

Fig 2: Morphometric measurements of hermit crab and its shell

3. Results and Discussions

A total of 2480 different types of gastropod shells were collected as samples and out of which 1230 gastropod shells were unchosen. Among the rest, twenty one shell species were identified. It has been observed that, only
two species of hermit crabs, namely, *Clibnarius padavensis* (Fig 3a) and *Clibnarius infraspinatus* (Fig. 3b) were occupied in all the twenty one gastropod shells as their microhabitats. Alcock (1905) [45] reported these two species for the first time from India.
These two crab species coexist in the sandy intertidal zone where *C. padavensis* prefer to forage in the mud flats of mohona region (upper intertidal zone) along with *Telescopium* shells in abundance. But *C. infraspinatus* was found to exist everywhere in the intertidal zone and their distribution is much more influenced by the distribution of empty gastropod shells. The shell use pattern as studied earlier in hermit crabs may vary and their coexistence may attribute to shell (Grant and Ulmer, 1974; Floeter *et al.,* 2000; Turra and Leite 2002; Oba *et al.,* 2008) [46, 47, 48, 49]. *Clibnarius infraspinatus* commonly known as orange striped hermit crab were moderate in number to that of *Clibnarius padavensis* as identified during laboratory study. But juveniles were difficult to identify specieswise and hence crab abundance was not analysed clearly.

(a) *Clibanarius padavensis* (b) *Clibanarius infraspinatus*

Fig 3: Two species of hermit crab from the Bay of Bengal (India).

Female hermit crabs were determined by the presence of gonopores (Fig4a) ventral to the cephalothoracic-abdominal junction of matured big crabs and by egg content on the pleopods (Fig 4b). Almost all the females are gravid with good quantity of bright, berried red eggs found on the pleopods of the crab (collected during the months of September and October). But females are less abundant in the muddy flats of Bakkhali beach relative to Fraserganj beach.

4a 4b 4c

Fig 4a: Gonopores in female crab (in red circle) **Fig 4b and 4c:** Gravid female crabs showing location of eggs

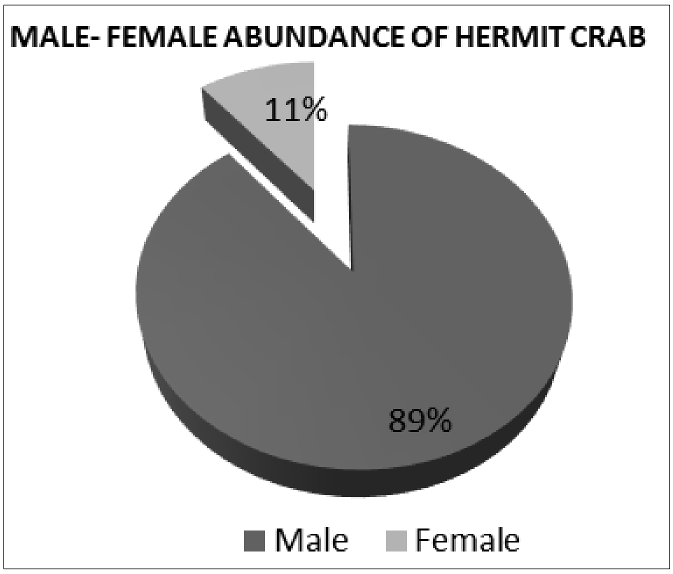

Fig 5: Male- female abundance of Hermit crabs

The gastropod shells during laboratory analysis showed that shells chosen by gravid females have less or no epibiotic coverings (barnacle colonies and scallops), but shells chosen by male crabs have more barnacle colonies and scallops ornamentation. The *Telescopium* shells have much elaborate ornamentations relative to other large shells. This epibionts increases the weight of the shells which is an extra load to bear with hermit crabs during foraging. Male crabs opt for shells with high epibiotic covering which may be a signal of honesty to be selected by female crabs during sexual selection. According to Bach *et al.* (1976) [16], the presence or absence of epibionts on shells has a strong effect on the shell use pattern in hermit species with lower shell selectivity.

Presence of secondary slit or opening in the chosen shells were found among all the gravid females which may be either for release of eggs or may be to facilitate effective respiration to the remote eggs within the shell Vermeij (2012) [50]. In other studies, high intertidal hermit crabs namely *Calcinus obscures* and *Clibanarius albidigitus* preferred highly spiral shells, because those shells hold more water and therefore prevent desiccation (Bertness, 1981a,b) [51, 52].

Fig 6: Shell opening showing secondary slits inside *T. telescopium* shell earlier inhabitated by gravid *C. padavensis.*

In the present study the relative percentage of chosen gastropod shells by hermit crabs was 50.4 and the unchosen percentage of gastropod shells was 49.6. Among the chosen shells, twenty one different types of gastropod shells were selected as the hermit microhabitat (Table 1), out of which eighteen are of marine molluscs and three species are fresh water molluscan shells.

Table 1: Diversity of different gastropod shells chosen by Hermit Crabs

Serial No.	Shell types Marine Molluscan Shells	Codes
1	*Nerita (Amphinerita) articulata Gould*	NB
2	*Cerithidea (Cerithidea) obtusa* Lamarck	CO
3	*Cerithidea (Cerithideopsilla) cingulated* (Gmelin)	PC
4	*Telescopium telescopium* (Linnaeus)	TT
5	*Polinices (Polinices) mamilla* (Linnaeus)	PM
6	*Polinices (Neverita) didyma* (Roeding)	ND
7	*Natica (Natica) tigrina* (Roeding)	NT
8	*Natica (Natica) vitellus* (Linnaeus)	NV
9	*Tonna dolium* (Linnaeus)	TD

10	*Gyrineum natator* (Roeding)	GN
11	*Bufonaria rana* (Linnaeus)	BR
12	*Thais blanfordi* (Melvill)	IB
13	*Thais lacera* (Born)	IL
14	*Nassarius (Niotha) stolatus* (Gmelin)	NS
15	*Nassarius (Zeuxis) foveolatus* (Dunker)	NF
16	*Pugilina (Hemifusus) cochlidium* (Linnaeus)	VC
17	*Turricula javana* (Linnaeus)	TJ
18	*Architectonica laevigata* (Lamarck)	AL
	Fresh Water Molluscan Shells	
19	*Bellamya bengalensis* (Mueller)	BB
20	*Pila globosa* (Swainson)	PG
21	*Melanoides tuberculata* (Mueller)	MT

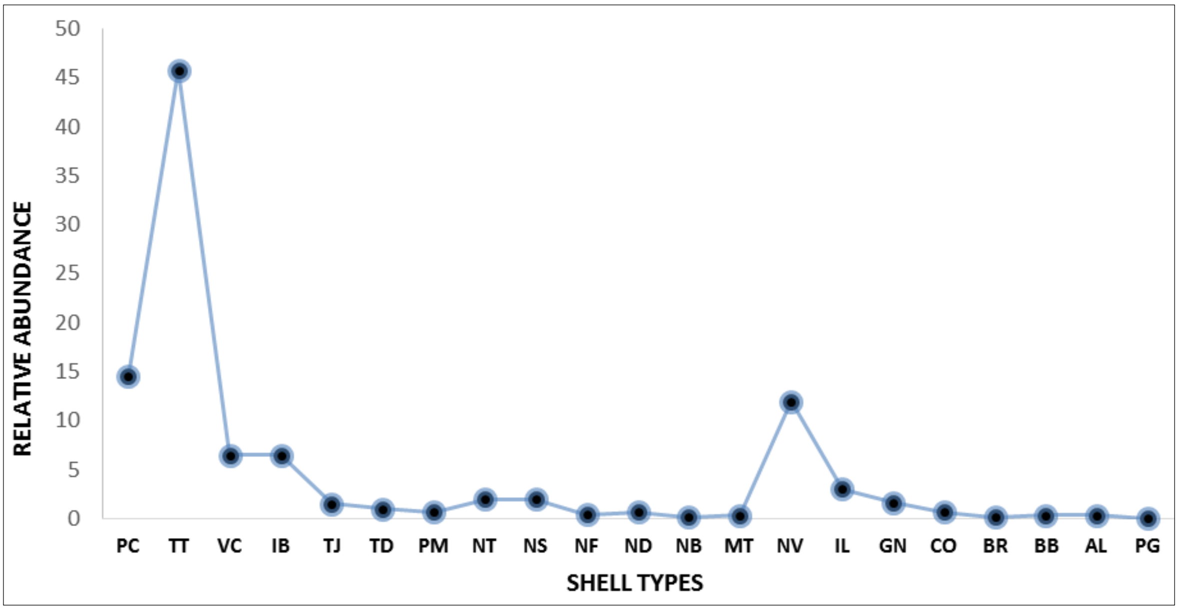

Fig 7: Relative abundance of different gastropod shells showing diversity for shell choice.

Availability of the twenty one different types of molluscan shells in the sandy shore of Bakkhali and Fraserganj showed that *Telescopium telescopium* (TT) is the most abundant shell type followed by *Cerithidea cingulate* (PC), *Natica vitellus* (NV), *Pugilina cochlidium* (VC), *Thais blanfordi* (IB) and *Thais lacera* (IL) respectively (Fig. 7). Hermit crabs opt for *Telescopium* first rather than the other shells due to its rich availability for their microhabitat and durability of the shells (described later). Although *Cerithidea* shells are highly abundant (smaller shells escaped collection) in the mud flat areas (mohona), their size and collumelar space is very narrow and cannot provide sufficient space as microhabitat except the juveniles. *Thais* shells have good columellar space and are lighter shells chosen as microhabitat which is moderately abundant. Big shells with large columellar space and light weight like *Tonna dolium*, *Pila globosa* are chosen by large size crabs whose abundance is low in the crabitat. As hermit crabs actively transport, recycle, and concentrate gastropod shells in this zone (Thompson *et al.*, 1985) [1], their preference of choice for a specific shell type is least rather shell supply by dying gastropods and other hermit crabs (Turra and Denadai, 2004) [53] regulates their occupancy for shells. Hence the choice of shells may be under competition for the two species of hermit crabs which is site specific depending on shell availability or may be some species of hermit have more preference for some shell types which may be innate behavior or learnt (shell use history) according to Elwood *et al.* (1979) [32]; Turra and Leite (2003) [35].

In the present study only three freshwater molluscan shells *Bellamya bengalensis*, *Pila globosa* and *Melanoides tuberculata* (these species are least concerned according to IUCN Red List of Threatened Species, 2017- 3) were found in this marine ecotone region which were also chosen by hermit crabs as their temporary refuge. These freshwater gastropod shells have entered into the marine environment by inundations and runoff. Those crabs sometimes inhabit allochthonous shell species and water currents added those freshwater shells into hermit habitat, also called as anomalous habitat of the organism (Shimoyama *et al.*, 1979; Yamaguchi, 1983; Asakura and Kikuchi, 1984; Shimoyama, 1985) [54, 55, 56, 57].

The quality of the shells and its composition is another important determinant for shell preferences in hermit crabs since shell health increases fitness of foraging, survivality, fecundity and reproductive success of the hermits inhabiting within it. Chemical erosions, wave actions, hydrodynamics (Hahn, 1998) [25], dilution of sea water (Davenport *et al.*, 1980) [26], chemical cues (Mesce, 1982; Benoit *et al.*, 1997) [27, 28], abrasion and extremes of temperature (Reese, 1969, Vance, 1972b) [29, 58] etc. act continuously on the shells in the nature for delimiting its quality against selection. Hence durability is an important criterion of the shells to be taken into consideration while studying the shell choice in hermit crabs. So only large and heavy shells which were moderately to highly abundant were taken for the durability test to determine the rate of decay or degradation (Fig. 8). Out of eleven shells VC showed the high rate of degradation while MT the least.

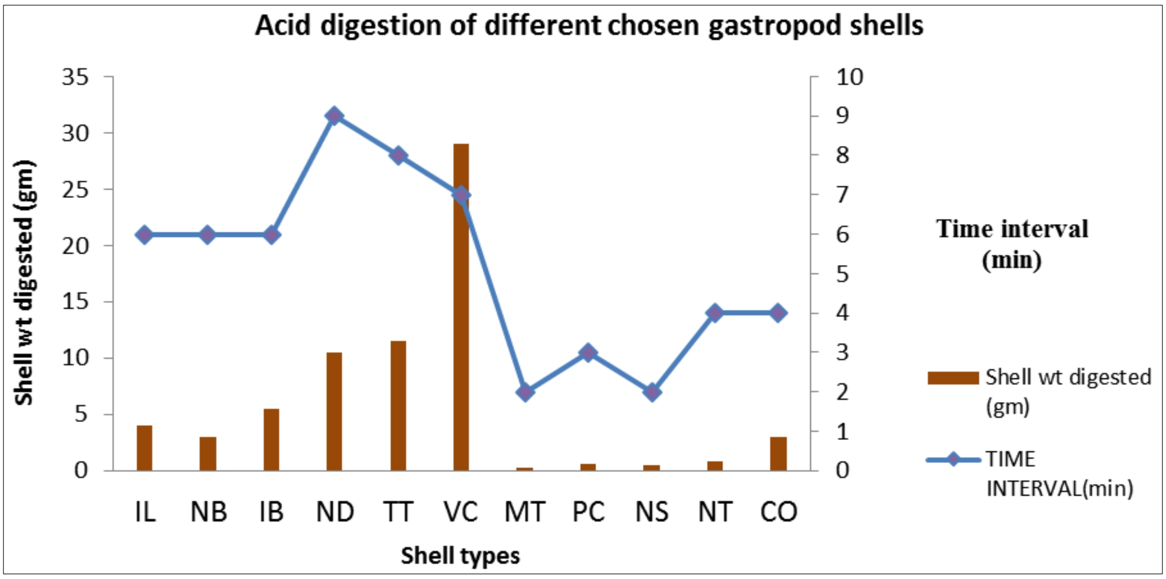

Fig 8: Acid digestion of selected Molluscan shells

After two-tailed single t-test, it was observed that the rate of shell digestion is varying significantly (t=2.722, df=10, $p< 0.05$) among different shell types. This indicates that different shell types have different chemical compositions on which the rate of digestion (ie. durability) depends.

Shells like MT, PC, NS, NT etc. have very low rate of decay of shells in HCl acid; hence are much durable shells (valued shells) in comparison to others due to change in some unknown chemical composition of the shells. Shells like VC, TT, ND etc. have high rate of decay; hence are poorer shells in durability test (low –valued shells). But the presence of hermit crabs was also observed in those low valued shells irrespective of their low durability indicating that, the availability of empty molluscan shells is low for shell choice due to unpredictability of the shell supply, a common situation in nature and severe competition may exist for the choice in the two species *C. padavensis* and *C. infraspinatus*. Hence absence of preference is found in hermit crabs for choosing such a diversity of twenty one different types of molluscan shells as their microhabitat.

The morphometric study of hermit crabs and its' molluscan shells (both chosen and unchosen) showed that there exists a positive correlation between crab weight (wt.) and shell weight (r= 0.536), ie. if the crab increases in size and in weight, it will opt for a new shell which is more heavier and larger than the previously chosen shell.

Table 2: ANOVA table to determine significance between chosen and unchosen shells.

Shell characters	F value	Significance
Shell length	25.893	p< 0.01
Shell weight	17.535	p< 0.01
Shell aperture length	87.379	p< 0.01
Shell aperture breadth	57.264	p< 0.01

The above ANOVA table (Table 2) showed that among the chosen and unchosen gastropod shells, four shell characters are varying at significant level ($p< 0.01$). This indicates that four shell characters (shell length, shell weight, shell aperture length and shell aperture breadth) have important influences on shell selection for these intertidal hermit crabs.

Table 3: Pearson correlation matrix between selected characters of female hermit crab and selected characters of their chosen shells

Female	TCL	CW	CAL	SL	SW	SAL	SAB	EW
TCL	1	0.950**	0.837**	0.705**	0.708**	0.897**	0.910**	-0.189
CW		1	0.829**	0.630**	0.652**	0.893**	0.929**	-0.148
CAL			1	0.826**	0.855**	0.663**	0.787**	0.086
SL				1	0.888**	0.527**	0.648**	0.194
SW					1	0.477**	0.669**	0.117
SAL						1	0.859**	-0.287*
SAB							1	-0.233
EW								1

(TCL= total crab length, CW= crab weight, CAL= crab abdominal length, SL= shell length, SW= shell weight, SAL= shell aperture length, SAB=shell aperture breath, EW=egg weight).

The above correlation table (Table 3) showed that crab length and shell length are positively correlated ($p< 0.01$) which indicates that with increase in body size of the hermit crabs, they opt for larger shells with increasing in volume. Similarly the crab wt. and shell wt. has high positive correlation (r= 0.652, $p< 0.01$) which states that if crab increases in size, its' weight increases, then choice for shell wt. will also increases. The shell aperture criteria (aperture length and aperture breadth) are also showing high positive correlation with crab wt. ($p< 0.01$) indicating that with the increase in crab size and wt., the shell aperture criteria also increases; hence they opt for larger shells with wide openings columellar space for easy accessibility.

Female hermit crabs with berried eggs showed a negative correlation with crab wt. and egg wt. which indicates that, crabs with lower body wt. can carry eggs easily. Female hermit crabs also showed negative correlation with shell aperture criterias (aperture length and breadth), indicating that they choose small aperture shells for more tightly fitting into it and to prevent slippage or unwrapping during foraging with its' eggs.

Table 4: Pearson correlation matrix between selected characters of male hermit crabs and selected characters of their chosen shells.

Male	TCL	CAL	SL	SW	SAL	SAB
TCL	1	0.826**	0.717**	0.634**	0.739**	0.607**
CAL		1	0.795**	0.716**	0.471**	0.577**
SL			1	0.819**	0.489**	0.615**
SW				1	0.462**	0.596**
SAL					1	0.611**
SAB						1

(TCL= total crab length, CW= crab weight, CAL= crab abdominal length, SL= shell length, SW= shell weight, SAL= shell aperture length, SAB=shell aperture breath, EW=egg weight).
** indicates values that are 99% correlated
*indicates values that are 95% correlated

Male hermit crabs showed all crab characters to be positively correlated (Table 4) with the shell characters ($p< 0.01$) indicating that male crabs not only choose optimal shell criterias but also carry excess load bearing epibiotic coverings in contrast to female choice for shells. These male specific criteria of shell choice may have an important role in sexual selection in the hermit crab population which needs to be observed in the nature for detail analysis.

4. Conclusions

The present study was an attempt to get an idea on the gastropod shell utilization pattern by two species of hermit crabs (*Clibnarius padavensis* and *Clibnarius infraspinatus*) from their natural habitat which is highly complicated. Various factors are responsible for the shell choice behaviours of hermit crabs which are multi-dimensional in nature. Shell use pattern in the natural habitat of Bay of Bengal is dependent on a combination of both site specific features (shell availability, silt deposition, beach exposure as foraging ground, wave action, predators, habitat complexity and shell use history) and preference of the crab species for shells. *C. padavensis* comparatively slender hermit crabs to that of *C. infraspinatus*, prefer to choose narrow columellar spaced, highly coiled shells like *Telescopium telescopium, Cerithidea cingulate* etc. and are found in abundant quantity on the Bakkhali mohona beach where the shore area is muddy due to siltation brought down from the back-water flow of the adjacent mangrove forest areas. But the other orange striped hermit crab *C. pad avensis* are found to forage from the upper intertidal zone to the extreme lower intertidal zone of the sandy shore (almost 1.5 km. exposed intertidal zone) which were found to inhabit within large columellar spaces of large shells like *Tonna dolium, Pugilina cochlidium, Thais lacera* etc. Thus both species selectivity for gastropod shells (innate shell preference or learnt behavior for optimal shell, valued shell choice from shell use history) and site specific selection (abundance of twenty one types of gastropod shells and richness of a specific type of shell in a particular area) exists in the study area.

Several workers like, Elwood *et al.* (1979) [32]; Borjesson and Szelistowski (1989) [59]; Liszka and Underwood (1990) [60]; Yoshino *et al.* (1999) [61]; Meireles and Mantelatto (2005) [62]; Sato and Jensen (2005) [63]; Bulinski (2007) [36]; Meireles *et al.* (2008) [64] have studied the shell selection pattern in hermit crabs within a single populations. However another group of workers like, Grant and Ulmer (1974) [46]; Abrams (1987) [65]; Gherardi (1990) [66]; Floeter *et al.* (2000) [47]; Turra and Leite (2002) [67]; Turra and Denadai (2004) [53]; Oba *et al.* (2008) [48]studied the shell selections in between sympatric species, where they have shown the shell selection by hermit crab is highly plastic.

Their best shell choice (optimal fit) as a microhabitat depend primarily on the quality of the shell and on characters like shell weight, shell length, shell aperture size, inner collumelar space, durability etc. The shell weight is the load that the crabs carry along with them after their hatching from the egg (juvenile) and continue till death. So the crab will opt for low weight, high durable shell providing good efficiency to carry the load so that shell acquired enhances fitness, increase survival and fecundity. Ornamentations like epibiotic shell covering and secondary slit/ opening are also the criteria for shell choice behaviour. But to understand the nature of shell selection in hermit crabs, not a single method of experimentation is sufficient. Hence the present study has only explained the nature of gastropod shell use in the natural habitat rather than shell selection.

5. Acknowledgements

Authors like to express their thanks and regards to the executive committee of Social Environmental and Biological Association (SEBA), Kolkata for their financial help in this communication. Authors also like to express their special thanks of gratitude to Principal Maharaj Swami Kamalasthananda and Controller of Examinations, Swami Vedanuragananda Maharaj of Ramakrishna Mission Vivekananda Centenery College for extending their all support to complete the project. Authors are also thankful to the scientists of Crustacea and Mollusca section, Zoological Survey of India, Kolkata for their kind cooperation in identification of species. Lastly a part of the acknowledgement also goes to Dr. Arunava Mukherjee, Dept of Zoology, RKMVC College, Rahara for his help in the preparation of the manuscript.

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