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Shell utilization pattern by the hermit crab *Diogenes custos* (Fabricius, 1798) along Gulf of Kachchh, Gujarat, India

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Abstract

Present work aims to study the gastropod shell utilization pattern of hermit crab *Diogenes custos* in the intertidal zone of Gulf of Kachchh, Gujarat, India. Hermit crab specimens were collected randomly during the low tide timings using hand picking method in February 2019 and November 2019. Data on abundance of common gastropod species were also collected using a quadrate sampling method. Hermit crab wet weight (HW) and their shield length (SL) (represent the size of the hermit crabs) were measured. Gastropod shells were identified up to species level and different morphological characters such as shell dry weight (DW), shell length (SHL), shell volume (SHV), shell aperture length (SAL), and shell aperture width (SAW) were measured. Total 2000 individuals of *D. custos*, 1171 males (58.6%), 763 females (38.1%) and 66 ovigerous females (3.3%) occupying 49 species of gastropods were collected. *Pollia undosa* (21.9%) was highly occupied by *D. custos* followed by *Cantharus spiralis* (14.5%), *Tenguella granulata* (9.9%), *Chicoreus virgineus* (6.45%), *Cerithium caeruleum* (6.05%) and *Nassarius distortus* (6.05%). Regression analysis carried out between *D. custos* morphological characters and gastropod shell morphological characters showed a strong relationship which suggests that shell architecture plays an important role in shell utilization pattern of *Diogenes custos*. The abundance of *Pollia undosa* was very high in the intertidal zone as compared to other commonly occupied gastropods species which also suggests that gastropod shell availability in the habitat also has pronounced effect on shell utilization pattern of *D. custos*.

Keywords: *Diogenes custos*, Shell occupation, Gastropod diversity, Gulf of Kachchh, Gujarat

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1 Introduction

Hermit crabs are significant and unique members of infraorder anomura that occupy empty gastropod shells to protect their uncalcified pleon (Vance, 1972; Hazlett, 1981). Hermit crabs occupy empty shells from the habitat and remain dependent on them for the most of their lifespan (Reese, 1969; Turra and Leite, 2000) because gastropod shell acts as a shelter against various biotic and abiotic factors (Hahn, 1998; Angel, 2000). Shell selection in hermit crab does not happen by chance but it is a very complex process which is based on the availability of gastropod shells, abundance of hermit crab species, predation risk (Reese, 1969; Conover, 1978) and some environmental factors such as tidal height, wave action, temperature, etc (Vermeij, 1976; Bertness, 1982) and the behavior of the species that coexist (Sant'Anna et al., 2012). During the life cycle, hermit crabs require increasingly larger shells which keep them constantly in search for appropriate shells (Bertness, 1981a). Almost all aspects of the biology of hermit crabs are affected by gastropod shells occupied by them (Arguelles et al., 2010). A heavier and robust shell may provide better protection from predation and wave action (Rittschof et al., 1995; Hahn, 1998) but increase the cost of locomotion and reduce reproductive success (Bertness, 1981b; Osorno et al., 1998; Arguelles et al., 2009). Selection of shell is usually based upon complex and interactive factors, including shell weight, architecture, volume, height, width, colour and aperture size (Mantelatto and Garcia, 2000) and hydrodynamic characteristics and presence of epibionts also (Hahn, 1998; Arguelles et al., 2009). According to Abrams (1978), the selection of shell is mainly dependent on three major factors which are, shell species, shell size, and shell condition. The abundance and mortality of gastropod species have pronounced effect on the shell preference by hermit crab while the shell architecture, generally determined by total length, aperture length and width are also important factors considered for shell utilization pattern (Bertness, 1980).

Gujarat is the state of India with the longest coastline (21%) and posses a variety of marine habitats like mangroves, coral reefs, rocky shores, mudflats, sandy shores and estuaries (Patgaonkar et al., 2012; Trivedi et al., 2015). The hermit crab diversity of the state accounts for 14 species (4 genera, 2 families) (Trivedi and Vachhrajani, 2017). Most of the ecological studies are conducted on hermit crabs population of Saurashtra coast (Vaghela and Kundu 2012; Desai and Mansuri 1989; Trivedi and Vachhrajani, 2014) and only a few studies are carried out from Gulf of Kachchh (Trivedi et al., 2012) which includes the study on spatiotemporal distribution and shell utilization pattern of intertidal hermit crabs (Jhala et al., 2017). The hermit crab species *Diogenes custos* (Fabricius, 1798) is having widespread distribution ranging from the intertidal habitats of Africa, Madagascar, Pakistan, eastern Australia and India as well (Rahayu, 2001; Mclaughlin and Holthuis, 2001; Siddiqui et al., 2004; Trivedi and Vachhrajani, 2017). Although studies are carried out on the distribution of this species its ecological aspects are not studied so far, so the present study was conducted to understand the pattern of shell utilization and shell abundance in the intertidal zone of Okha located on the southern part of Gulf of Kachchh, Gujarat, India. The study also aims to understand the effects of shell architecture and the abundance of gastropod shells in the habitat on the shell utilization pattern of *Diogenes custos*.

2 Materials and Methods

2.1 Study area

The present study was conducted in the intertidal zone of Okha (22°28'32" N, 69°04'50" E) (Fig. 1) located in the Dwarka district and forms the southern part of Gulf of Kachchh, Gujarat.

The intertidal zone of Okha is characterized by rocks which form the upper intertidal zone with sand deposit areas in the middle and lower intertidal zone (Subba Rao and Sastry, 2005). This sand deposit areas support a healthy population of *D. custos*.

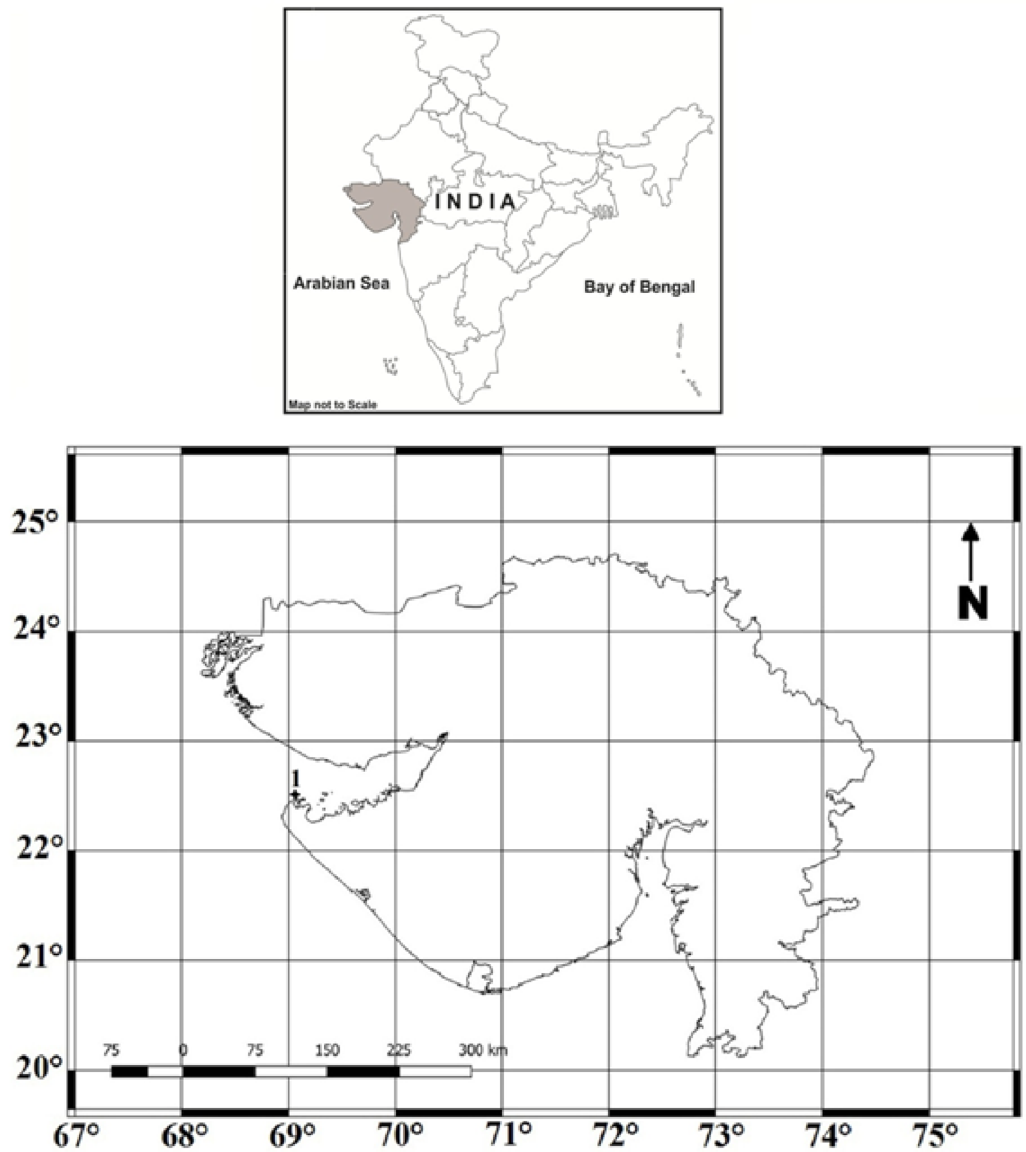

Figure 1. Map of study area. 1. Okha.

2.2 Sampling method

Hermit crab specimens were collected randomly using hand picking method during low tide in February and November 2019. All the specimens were kept in the icebox and brought to the laboratory for further analysis. Around 100 quadrates (0.25 m^2) were laid randomly from upper to lower intertidal zone to record data about abundance of common gastropod species in the intertidal zone. Hermit crabs were gently pulled out from their shells by slowly twisting the crab against the direction of the shell spiral and only intact individuals were used for the study. Sex was identified of all individuals by examining them under a stereo microscope and were separated as male, non-ovigerous female and ovigerous female.

Gastropod shells were identified up to species level using monograph by Apte (1998). Two morphological parameters were recorded for the sampled hermit crabs, hermit crab wet weight (HW) using weighing balance (0.01g) and shield length (SL), from the midpoint of the rostrum to the midpoint of the posterior margin of the shield (indicates the size of hermit crab) using vernier caliper (0.01mm). For gastropod shells, five parameters were considered which are as follows: Shell total length (SHL) from the tip of the apex to the base. Shell aperture length (SAL) maximum length of the opening of a gastropod shell parallel to the shell length. Shell aperture width (SAW) maximum distance between the outer margin of outer opening and inner wall of the inner lip, perpendicular to aperture length. For dry weight (DW) the shells were dried at 60°C for 24 h and weighed. For shell volume (SHV) empty shell was filled with water by a syringe (0.1 ml) till the edges of the aperture and the total volume of water filled is considered as the shell volume (mm^3) (Ragagnin et al., 2018). Regression analysis was carried out to find out the relationship between the different morphological characters of hermit crab and gastropod shell morphology. Variation in mean values of shield length of different sexes (males, non-ovigerous females and ovigerous females) of hermit crabs was analyzed using one way ANOVA. The shell species occupation was estimated in percentage and chi-square test (χ^2) was used to compare the occupancy percentage of different shell species by *D. custos*.

3 Results

A total of 2000 individuals of *Diogenes custos* were examined out of which, 1171 were males (58.6%), 763 were non-ovigerous females (38.1%) and 66 were ovigerous females (3.3%). Males were significantly larger than non ovigerous females and ovigerous female (Table 1). Male individuals were recorded in size classes ranging from 1.0 to 11.0 mm SL with maximum number of individuals recorded in 2.0 to 3.0 mm SL size class while non-ovigerous females were recorded in size classes ranging from 0.1 to 10.0 mm SL with maximum number of individuals recorded in 2.0 to 3.0 mm SL size class. Ovigerous females were recorded in size classes ranging from 2.0 to 5.0 mm SL and 6.0 to 8.0 mm SL with maximum number of individuals recorded in 3.0 to 4.0 mm SL size class (Fig. 2).

Table 1. Carapace shield length values of *Diogenes custos*. (***$p < 0.0001$) (SL= Sheild length).

Sex	Minimum SL (mm)	Maximum SL (mm)	Mean ± SD(mm)
Male	1.35	10.05	5.36 ± 2.28***
Non-ovigerous female	0.95	9.95	4.25 ± 2.02***
Ovigerous female	2.87	8.03	4.93 ± 1.63***

Individuals of *D. custos* were found occupying 49 species of gastropod shells in different percentages, among them 45 gastropod shell species were utilized by males, 42 species were utilized by non-ovigerous females and 11 species were utilized by ovigerous females. Six species of gastropod shells were highly utilized by *D. custos* population. *Pollia undosa* (21.9%) was the highest occupied gastropod species followed by *Cantharus spiralis* (14.5%), *Tenguella granulata* (9.9%), *Chicoreus virgineus* (6.45%), *Cerithium caeruleum* (6.05%) and *Nassarius distortus* (6.05%) (Table 2).

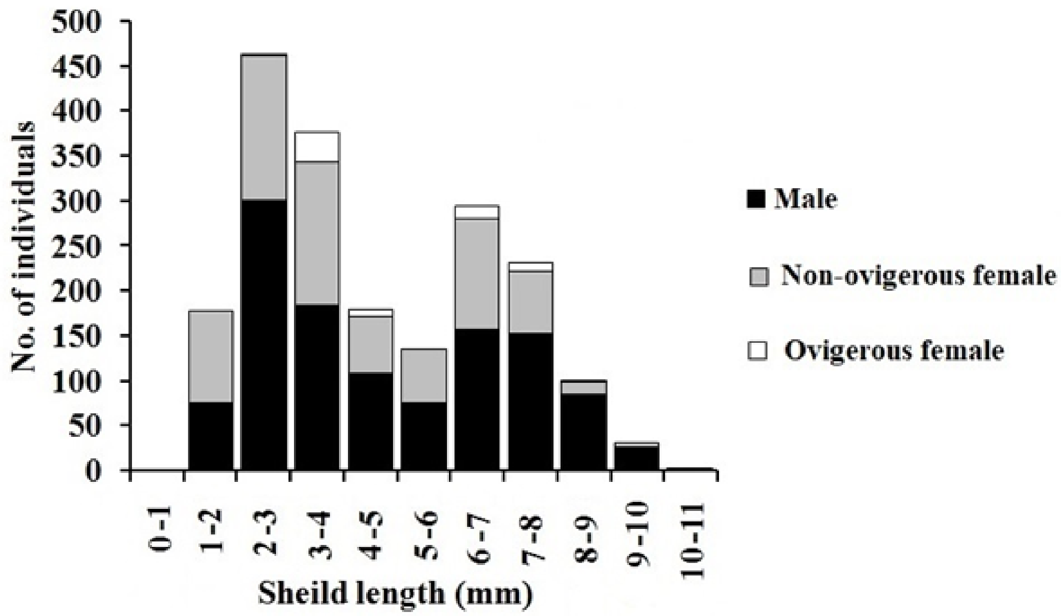

Figure 1. Size frequency distribution of different individuals (males, non-ovigerous females and ovigerous females) of *Diogenes custos*.

The variation in percentage occupation of these six species of gastropod was significantly different ($\chi^2 = 18.54$, $p<0.01$). The remaining gastropod species (termed as "others") contributed 35.15 % of total gastropod shell occupation and their occupation percentage varied from 0.05% to 3.6 % (Table 2). Percentage occupation of these six highly occupied gastropod shell species also varied significantly for different sexes of D. custos (male, $\chi^2 = 14.00$, $p < 0.01$; non-ovigerous female, $\chi^2 = 24.18$, $p < 0.001$; ovigerous female, $\chi^2 = 146.14$, $p < 0.0001$).

Table 2. Gastropod shell utilization by *Diogenes custos*. (N= total individuals; M = Male; F = non-ovigerous female; OF= ovigerous Female).

Gastropod species	N	%	M	%	F	%	OF	%
Pollia undosa (Linnaeus,1758)	438	21.90	217	18.53	188	24.64	33	50.00
Cantharus spiralis (Gray, 1839)	290	14.50	161	13.75	113	14.81	16	24.24
Tenguella granulate (Duclos, 1832)	198	9.9	127	10.85	67	8.78	4	6.06
Chicoreus virgineus (Roding, 1798)	129	6.45	85	7.26	42	5.50	2	3.03
Cerithium caeruleum (G.B.Sowerby,1855)	121	6.05	76	6.49	45	5.9	0	0.00
Nassarius distortus (Quoy & Gaimard, 1833)	121	6.05	68	5.81	53	6.95	0	0.00
Others	**703**	**35.15**	**437**	**37.32**	**255**	**33.42**	**11**	**16.67**
Turbo bruneus (Roding, 1798)	109	5.45	90	7.69	19	2.49	0	0.00
Indothais lacera (Born, 1778)	72	3.6	43	3.67	25	3.28	4	6.06
Anachis terpsichore (G. B. Sowerby 2, 1822)	50	2.5	0	0.00	50	6.55	0	0.00
Chicoreus brunneus (Link, 1807)	44	2.2	23	1.96	20	2.62	1	1.52
Lunella coronata (Gmelin, 1791)	44	2.2	26	2.22	18	2.36	0	0.00
Ergalatax contracta (Reeve, 1846)	39	1.95	24	2.05	13	1.70	2	3.03

Gastropod species	N	%	M	%	F	%	OF	%
Semiricinula tissoti (Petit de la saussaye,1852)	38	1.9	26	2.22	12	1.57	0	0.00
Planaxis sulcutus (Born,1778)	36	1.8	27	2.31	9	1.18	0	0.00
Chicoreus ramosus (Linneus, 1758)	29	1.45	18	1.54	11	1.44	0	0.00
Nassarius marmoreus (A. Adams, 1852)	29	1.45	23	1.96	5	0.66	1	1.52
Nassarius nodifer (Dunker, 1847)	21	1.05	18	1.54	3	0.39	0	0.00
Gyrineum natator (Roding, 1798)	17	0.85	5	0.43	12	1.57	0	0.00
Semiricinula konkanensis (Melvill, 1893)	17	0.85	10	0.85	7	0.92	0	0.00
Chicoreus mauraus (Broderip, 1833)	16	0.8	13	1.11	3	0.39	0	0.00
Nassarius pullus (Linnaeus, 1758)	15	0.75	8	0.68	6	0.79	1	1.52
Nassarius reeveanus (Dunker, 1847)	15	0.75	11	0.94	3	0.39	1	1.52
Purpura panama (Roding, 1798)	14	0.7	9	0.77	5	0.66	0	0.00
Indothais sacellum (Gmelin, 1791)	13	0.65	5	0.43	7	0.92	1	1.52
Murex haustellum (Linneus , 1758)	8	0.4	7	0.60	1	0.13	0	0.00
Babylonia spirata (Linnaeus, 1758)	7	0.35	5	0.43	2	0.26	0	0.00
Tutufa bufo (Roding, 1798)	7	0.35	6	0.51	1	0.13	0	0.00
Littorina sp.	5	0.25	1	0.09	4	0.52	0	0.00
Reticutriton pfeifferianus (Reeve, 1844)	6	0.3	4	0.34	2	0.26	0	0.00
Volegalea cochlidium (Linnaeus, 1758)	6	0.3	4	0.34	2	0.26	0	0.00
Monoplex aquatilis (Reeve, 1844)	5	0.25	4	0.34	1	0.13	0	0.00
Murex ternispina (Lamark, 1822)	4	0.2	3	0.26	1	0.13	0	0.00
Pollia rubiginosa (Reeve, 1846)	4	0.2	3	0.26	1	0.13	0	0.00
Astralium stellar (Gmelin, 1791)	3	0.15	2	0.17	1	0.13	0	0.00
Bufonaria echinata (Link, 1807)	3	0.15	2	0.17	1	0.13	0	0.00
Clypeomorus batillariaeformis (Habe & Kosuge, 1966)	3	0.15	1	0.09	2	0.26	0	0.00
Echinolittorina pascua (Rosewater, 1970)	3	0.15	2	0.17	1	0.13	0	0.00
Monodonta australis (Lamarck, 1822)	3	0.15	3	0.26	0	0.00	0	0.00
Monoplex pilearis (Linnaeus, 1758)	3	0.15	3	0.26	0	0.00	0	0.00
Paradrillia patruelis (E.A.Smith,1875)	3	0.15	0	0.00	3	0.39	0	0.00
Cerithium columna (Sowerby I, 1834)	2	0.1	2	0.17	0	0.00	0	0.00
Tibia insulaechorab (Roding, 1798)	2	0.1	1	0.09	1	0.13	0	0.00
Turricula tornata (Dillwyn, 1817)	2	0.1	1	0.09	1	0.13	0	0.00
Mitra scutulata (Gmelin, 1791)	1	0.05	1	0.09	0	0.00	0	0.00
Mitrellablanda (G.B.Sowerby 1, 1844)	1	0.05	1	0.09	0	0.00	0	0.00

Gastropod species	N	%	M	%	F	%	OF	%
Purpura bufo (Lamarck, 1822)	1	0.05	1	0.09	0	0.00	0	0.00
Pyrene flava (Bruguiere, 1789)	1	0.05	1	0.09	0	0.00	0	0.00
Turricula javana (Linnaeus, 1767)	1	0.05	0	0.00	1	0.13	0	0.00
Turritella radula (Kiener, 1843)	1	0.05	0	0.00	1	0.13	0	0.00
Total	**2000**		**1171**		**763**		**66**	

Pollia undosa shells were most commonly utilized by *D. custos* individuals recorded in size classes ranging from 1.0 to 6.0 mm SL with maximum utilization recorded in size classes 3.0 to 4.0 mm SL. *Cantharus spiralis* and *Chicoreus virgineus* shells were also commonly utilized by larger *D. custos* individuals recorded in size classes ranging from 1.0 to 10.0 mm SL. T*enguella grenulata* shells were also utilized by *D. custos* individuals recorded in size classes ranging from 1.01 to 5.0 mm SL with maximum utilization recorded for smaller individuals falling in size class 2.0 to 3.0 mm SL. *Cerithium caeruleum* and *Nassarius distortus* shells were utilized by smaller *D. custos* individuals recorded in size classes ranging from 1.0 to 5.0 mm SL with maximum utilization recorded in size classes 2.0 to 3.0 mm SL. Gastropod shell species belonging to "others" group were commonly utilized by individuals belonging to all the size classes (Fig. 3).

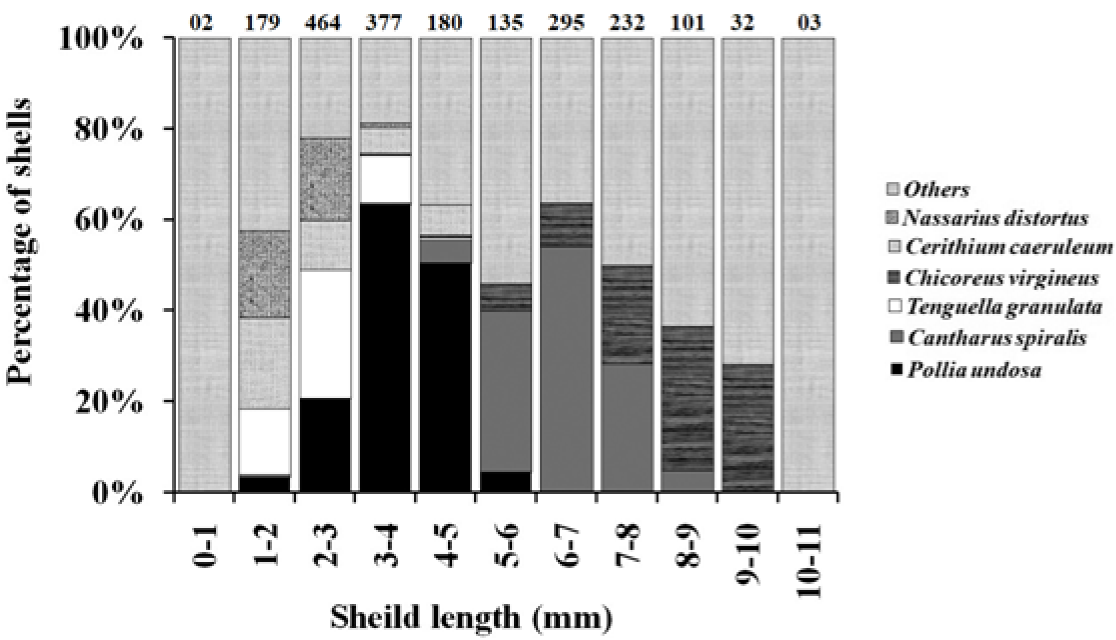

Figure 3. Use of gastropod shell species by individuals of *Diogenes custos* of different size classes. (Numbers above the bar indicates number of individuals).

Shield length (SL) of *D. custos* showed a significant relationship with all the morphological parameters of gastropod shells in which maximum value of relationship was found for SHL, SAL and SAW (Fig. 4). Hermit crab wet weight (HW) of *D. custos* also showed a significant relationship with all morphological parameters of gastropod shells, amongst which maximum value of relationship was found for SAL and SAW (Fig. 5). Regression analysis between SL of male, non- ovigerous and ovigerous and SHL and SAW showed the highest values of relationship as compared to other morphological characters of highly utilized gastropod species (Table 3). Amongst the highly occupied gastropod species by *D. custos*, the abundance of *P. undosa* was recorded maximum followed by *C. spiralis*, *T. granulata*, *C. virgineus*, *C. caeruleum*, *N. distortus*, *T. bruneus* and *I. lacera* in the intertidal zone of Okha (Fig. 6).

Table 3. Regression equation in relation to morphological factors of different sexes of *Diogenes custos* and that of gastropod shells measures (*P < 0.01; **P<0.001; ***P<0.0001; Shield length= SL; Hermit crab wet weight= HW; Shell length= SHL; Shell aperture length= SAL; Shell aperture width= SAW; Shell dry weight= DW; Shell volume= SHV).

Sex	N	Relationship	Y= axb	ln y= a+b ln x	R2
Male	1171	SL × SHL	SHL= $11.12SL^{0.194}$	SHL = -6.18 + 26.10 lnSL	0.84***
		SL × SAL	SAL= $3.83SL^{0.189}$	SAL = -1.73 + 8.54 lnSL	0.85**
		SL × SAW	SAW= $1.87SL^{0.242}$	SAW = -3.35+ 7.25lnSL	0.73***
		SL × DW	DW= $0.27SL^{0.528}$	DW = -10.72 + 12.23 lnSL	0.75
		SL × SHV	SHV= $0.08SL^{0.558}$	SHV = -4.29 + 4.76 lnSL	0.56
		HW × SHL	SHL= $20.05HW^{0.228}$	SHL = 35.39 + 8.87 lnHW	0.69***
		HW × SAL	SAL= $6.76HW^{0.230}$	SAL = 11.88 + 2.95 lnHW	0.77***
		HW × SAW	SAW= $3.84HW^{0.296}$	SAW = 8.21 + 2.49 lnHW	0.68***
		HW × DW	DW= $1.34HW^{0.628}$	DW = 8.78 + 4.20 InHW	0.73***
		HW × SHV	SHV= $0.42HW^{0.677}$	SHV = 3.31 + 1.66 lnHW	0.61***
Non ovigerous female	763	SL × SHL	SHL= $10.57SL^{0.207}$	SHL = -1.92+ 22.77 lnSL	0.85*
		SL × SAL	SAL= $3.46SL^{0.207}$	SAL = -4.43 + 7.30 lnSL	0.87
		SL × SAW	SAW= $1.64SL^{0.265}$	SAW = -1.89 + 5.91 lnSL	0.83***
		SL × DW	DW= $0.20SL^{0.596}$	DW = -7.40 + 9.49 lnSL	0.72***
		SL × SHV	SHV= $0.06SL^{0.609}$	SHV = -2.51 + 3.23 lnSL	0.70***
		HW × SHL	SHL= $18.77HW^{0.308}$	SHL = 34.68 + 7.81 lnHW	0.65***
		HW × SAL	SAL= $6.13HW^{0.311}$	SAL = 11.33 + 2.53 lnHW	0.70***
		HW × SAW	SAW= $3.40HW^{0.397}$	SAW = 7.62 + 2.04 lnHW	0.69***
		HW × DW	DW= $1.03HW^{0.890}$	DW = 7.86 + 3.26lnHW	0.64***
		HW × SHV	SHV=$0.33HW^{0.913}$	SHV = 2.69 + 1.12 lnHW	0.65***
Ovigerous female	66	SL × SHL	SHL= $12.90SL^{0.170}$	SHL = -13.10 + 28.72 lnSL	0.91
		SL × SAL	SAL= $4.17SL^{0.170}$	SAL = -4.25 + 9.30 lnSL	0.88
		SL × SAW	SAW= $2.12SL^{0.204}$	SAW = -4.42 + 6.88 lnSL	0.91***
		SL × DW	DW= $0.27SL^{0.534}$	DW = -19.88 + 16.73 lnSL	0.74***
		SL × SHV	SHV= $0.11SL^{0.481}$	SHV = -5.11 + 4.44 lnSL	0.75***
		HW × SHL	SHL= $24.05HW^{0.156}$	SHL = 32.19 + 7.71 lnHW	0.45***
		HW × SAL	SAL= $7.77HW^{0.155}$	SAL = 10.40 + 2.48 lnHW	0.44**
		HW × SAW	SAW= $4.42HW^{0.1.96}$	SAW = 6.42 + 1.89 lnHW	0.50**
		HW × DW	DW= $1.87HW^{0.507}$	DW = 6.51 + 4.53 lnHW	0.42***
		HW × SHV	SHV= $0.66HW^{0.433}$	SHV = 1.89 + 1.15 lnHW	0.34**

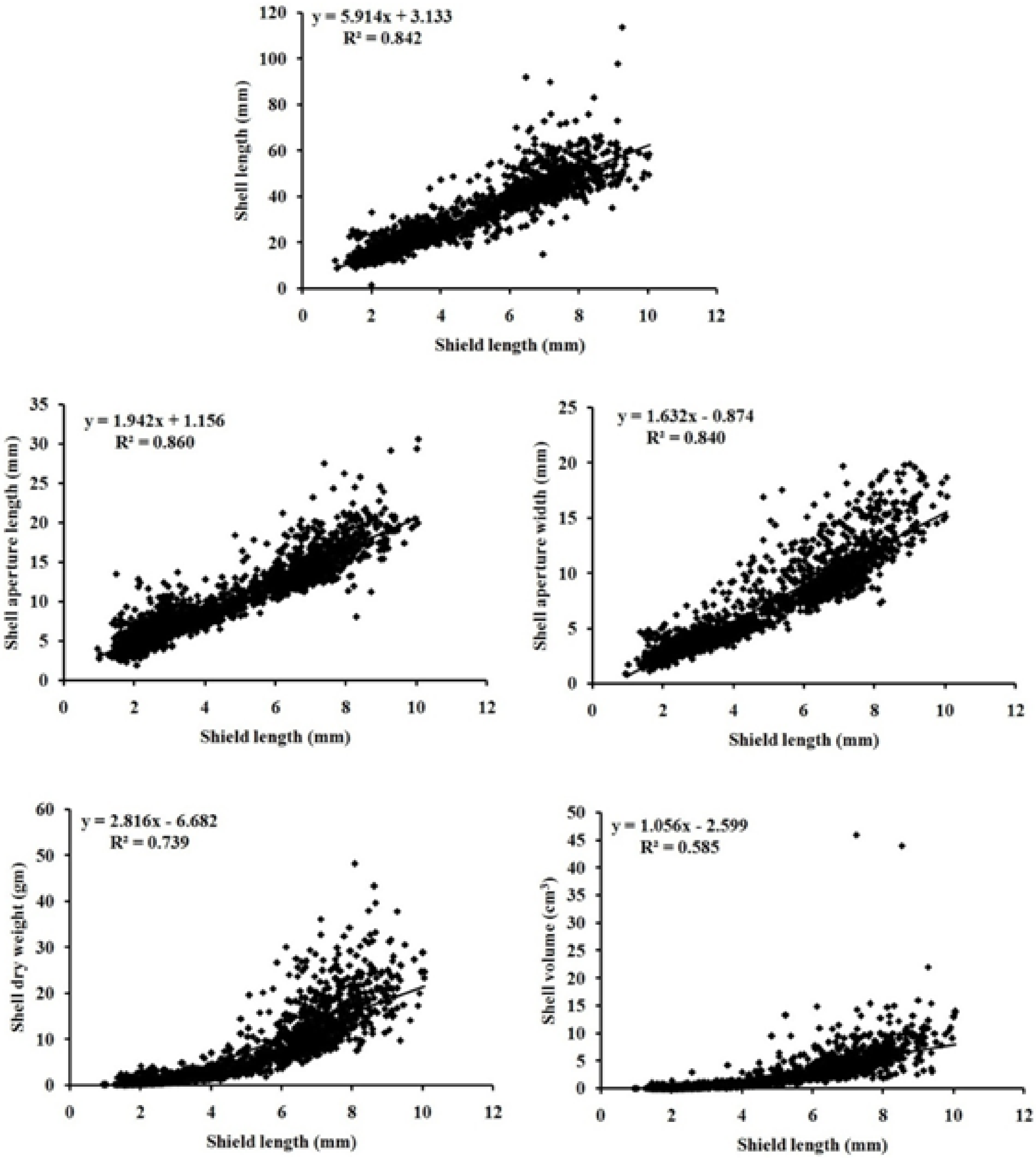

Figure 4. Regression analysis between different morphological factors of gastropod shells and *Diogenes custos* shield length (mm).

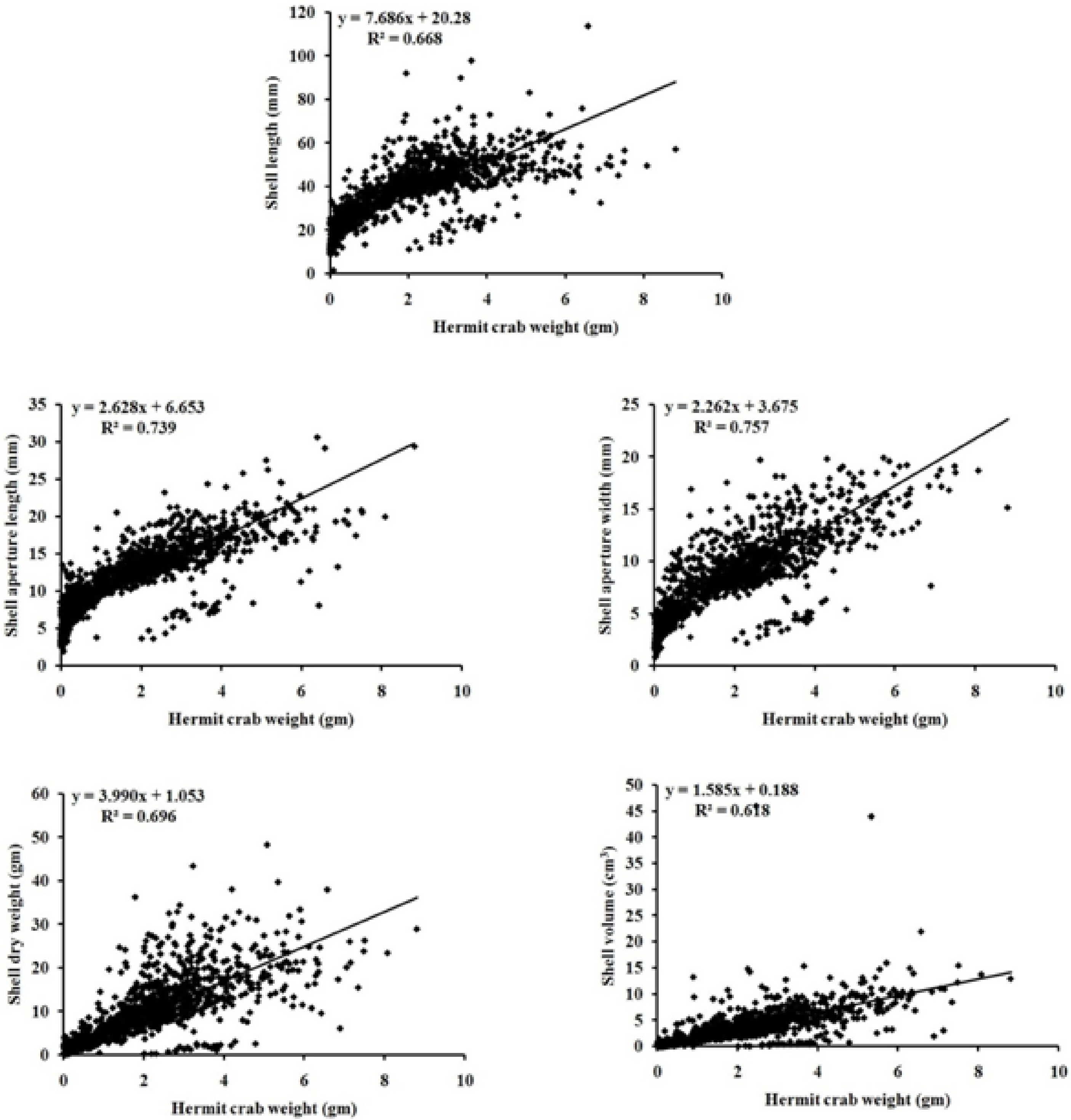

Figure 5. Regression analysis between different morphological factors of gastropod shells and *Diogenes custos* weight (gm).

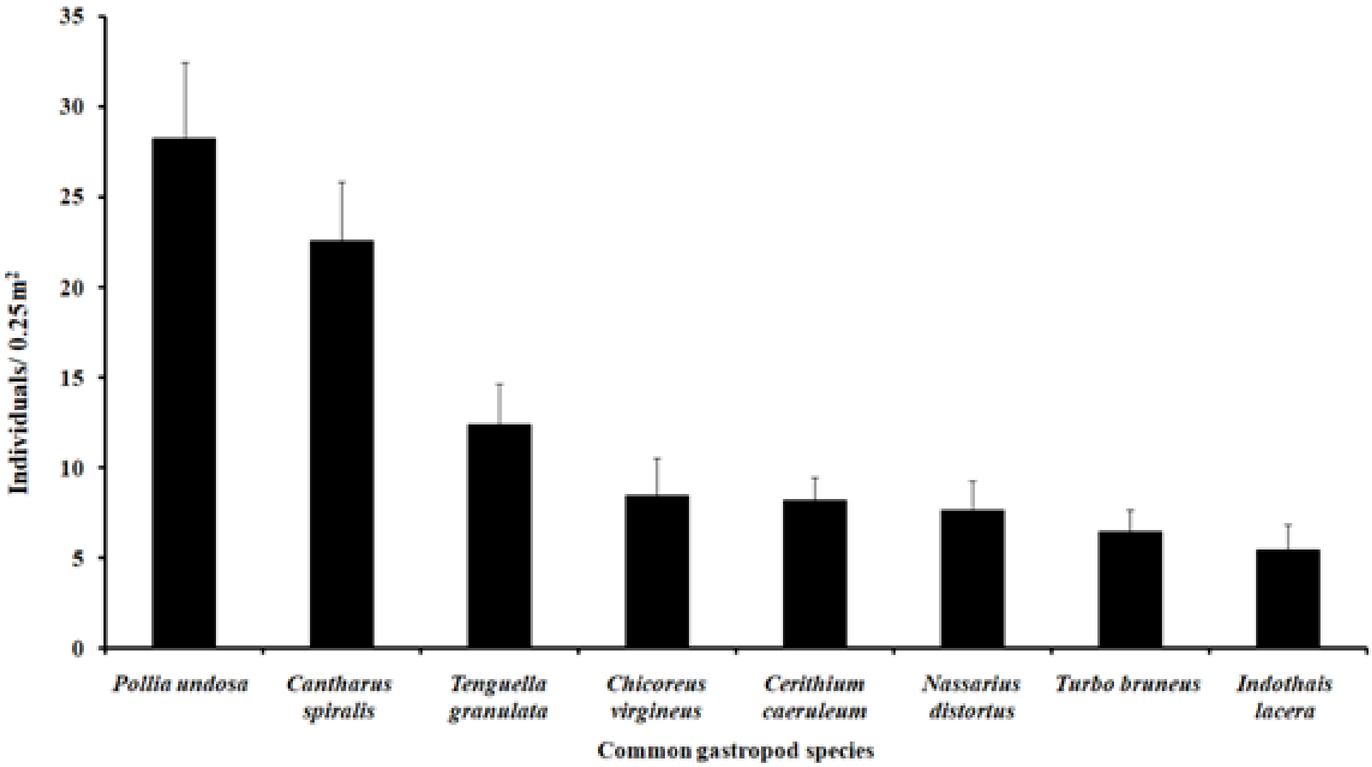

Figure6. Abundance of common gastropod species in intertidal zone of Okha.

4 Discussion

Gastropod shells serve as a mobile home and provide protection against predation, desiccation and from other hermit crabs (Provenzano, 1960; Hazlett, 1981). Shell selection is usually based on complex and interactive factors, including shell weight, volume, height, width, colour and aperture size (Garcia and Mantelatto, 2000, 2001) and also based on shape, hydrodynamic characteristics and presence of epibionts (Hahn, 1998; Arguelles et al., 2009). In the present study it was found that the hermit crab species *D. custos* occupies 49 species of gastropod shells (Table 2) which is very much higher as compared to gastropod species occupied by other species like *Diogenes gardineri* (16 species) (Orians and King, 1964), *D. pugilator* (27 species) (Mutlu and Ergev, 2010), *D. brevirostris* (33 species) (Emmerson and Alexander, 2010) and *D. planimanus* (32 species) (Fatima, 2007). In the present study, ovigerous females of *D. custos* occupied only 11 species of shells which is very less as compared to males (45 species) and non-ovigerous females (42 species). Similar results were observed for ovigerous females of *D. puligator* (Manjón-Cabeza and Raso, 1999), *Clibanarius vittatus* (Sant'Anna et al., 2006) and *Clibanarius zebra* (Trivedi and Vachhrajani, 2014) which suggest that ovigerous female are selective for specific shells with larger internal space suitable for accommodating eggs during the breeding season (Bertness, 1981b; Sallam, 2012).

Different morphological parameters of gastropod shells show a strong relationship with SL and HW of hermit crabs occupying those shells (Fotheringham, 1976; Conover, 1978; Sant'Anna et al., 2006; Ismail, 2010). In the present study, regression analysis was carried out between morphological parameters of hermit crab and gastropod shell, where the SL of different sexes (male, non-ovigerous and ovigerous female) of *D. custos* showed high correlation with SHL, SAL and SAW of gastropod shells (Figs. 4, 5; Table 3). Similar results were also observed for other hermit crab species like *Clibanarius erythropus* (Caruso and Chemello, 2009), *C. latens* and *C. signatus*, (Ismail, 2010). Such studies suggest that occupying heavy and larger shells, hermit crabs get protection from predators, intense wave action and desiccation (Reese, 1969; Brown and McLachlan, 2002). It has been observed that the shell total length, aperture length and aperture width are more directly related to the shell architecture than shell weight which shows that hermit crabs are more selective for shell species (architecture) as compared to shell weight (Turra and Leite, 2002). *Diogenes custos* is found in sandy patches of rocky shores where intense wave action and high temperature during the low tide affects a lot. It is also suggested that the appropriate length and width of the aperture of gastropod shell makes the movement of resident hermit crab easier (Conover, 1978; Sant'Anna et al., 2006; Ismail, 2010).

In the present study, it was observed that males and ovigerous females are larger in size as compared to non-ovigerous females (Table 1). Ovigerous females were found occupying larger shells as compared to non-ovigerous females. Similar results were observed in other species of hermit crabs like *D. puligator* (Manjón-Cabeza and Raso, 1999), *D. nitidimanus* (Asakura, 1995) and *Calcinus laevimanus*, *C. latens* and *Clibanarius humilis* (Nardone and Gherardi, 1997). Generally male occupy larger and robust gastropod shells as they utilize most part of their energy in physical growth whereas female occupies smaller gastropods since they save energy for the purpose of reproduction and egg development. However, ovigerous females are found to occupy larger and voluminous shells as compared to non-ovigerous females as they require more internal space to accommodate and protect their egg mass form predators and desiccation (Fotheringham, 1976; Abrams, 1978; Wilber, 1989; Mantelatto and Garcia, 2000).

In the present study, *D. custos* showed high preference for *P. undosa* shells, which is possible due to high abundance of *P. undosa* (Fig. 6) in the study area as compared to other commonly used gastropod species. A similar pattern of shell preference has been observed for *C. zebra* preferring *Cerithium scabridum* shell (Trivedi and Vachhrajani, 2014) and *Isocheles sawayai* preferring *Stramonita haemastoma* shell (Fantucci et al., 2008). It has been observed that the availability and abundance of gastropod shells in habitat affects gastropod shell utilization preference of hermit crabs (Kellogg, 1976; Scully, 1979; Barnes, 1999). In the present study, it was also observed that the gastropod species *P. undosa* was acquired by almost all size class of *D. custos* (Fig. 3) indicating wide availability of shells of this species in intertidal zone of the study site. It was also observed that the shells of *C. spiralis* and *C. virgineus* were occupied by individuals belonging to various size classes ranging from 1.0 to 9.00 mm and 3.0 to 10.00 mm SL which suggests strong competition between *D. custos* individuals belonging to different size classes. Occupying larger and stronger shell have various benefits which include protection from predation, cannibalism, desiccation, intra or inter specific fights, courtship and egg mass protection (Hazlett, 1981; Taylor, 1981; Shih and Mok, 2000; Pechenik et al., 2001). The pattern of shell utilization is greatly affected by various other factors also including individual size, reproductive status, growth and energy expenditure of individuals (Bertness 1981a; Mantelatto and Garcia, 2000; Turra and Leite, 2003; Dominciano and Mantelatto, 2004).

The current study provides a first insight into the ecological aspect of *D. custos* inhabiting sandy patches of the rocky intertidal zone of Gulf of Kachchh, Gujarat state, India. Further studies like intertidal distribution, population ecology, and spacio-temporal variation in the shell use pattern are required to understand the ecology of *D. custos* in the study area.

Conflict of interests

The authors declare that they have no conflicts of interest.

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References

Abrams, P. (1978). Shell selection and utilization in a terrestrial hermit crab, *Coenobita compressus* (H. Milne Edwards). Oecologia, 34, 239–253.

Angel, J.E. (2000). Effects of shell fit on the biology of the hermit crab *Pagurus longicarpus* (Say). Journal of Experimental Marine Biology and Ecology, 243(2), 169–184.

Apte, D. (1998). The Book of Indian Shells. Bombay Natural History Society. 162 pp.

Argüelles, A., Álvarez, F., & Alcaraz, G. (2009). Shell architecture and its relation to shell occupation by the hermit crab Clibanarius antillensis under different wave action conditions. Scientia Marina, 73(4), 717–723.

Argüelles-Ticó, A., Álvarez, F., & Alcaraz, G. (2010). Shell utilization by the hermit crab *Clibanarius antillensis* Stimpson, 1862 (Crustacea Anomura) in intertidal rocky pools at Montepio, Veracruz, Mexico. Tropical Zoology, 23(1), 63–73.

Asakura, A. (1995). Sexual differences in life history and resource utilization by the hermit crab. Ecology, 76(7), 2295–2313.

Barnes, D.K. (1999). Ecology of tropical hermit crabs at Quirimba Island, Mozambique: shell characteristics and utilisation. Marine Ecology Progress Series, 183, 241–251.

Bertness, M.D. (1980). Shell preference and utilization patterns in littoral hermit crabs of the Bay of Panama. Journal of Experimental Marine Biology and Ecology, 48(1), 1–16.

Bertness, M.D. (1981a). Predation, physical stress, and the organization of a tropical rocky intertidal hermit crab community. Ecology, 62(2), 411–425.

Bertness, M.D. (1981b). The influence of shell-type on hermit crab growth rate and clutch size (Decapoda, Anomura). Crustaceana, 197–205.

Bertness, M.D. (1982). Shell utilization, predation pressure, and thermal stress in Panamanian hermit crabs: an interoceanic comparison. Journal of Experimental Marine Biology and Ecology, 64(2), 159–187.

Brown, A.C., & McLachlan, A. (2002). Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. Environmental Conservation, 29(1), 62–77.

Caruso, T., & Chemello, R. (2009). The size and shape of shells used by hermit crabs: a multivariate analysis of *Clibanarius erythropus*. Acta Oecologica, 35(3), 349–354.

Conover, M.R. (1978). The importance of various shell characteristics to the shell-selection behavior of hermit crabs. Journal of Experimental Marine Biology and Ecology, 32(2), 131–142.

Desai, A.Y., & Mansuri, A.P. (1989). Salinity and desiccation tolerance of hermit crab of Veraval, West coast of India. Indian Journal of Current Biosciences, 8, 129–132.

Dominciano, L.C., & Mantelatto, F.L. (2004). The influence of shell species and size on the shell selection pattern of *Paguristes tortugae* (Decapoda, Diogenidae) from Anchieta Island (Ubatuba, Brazil). Iheringia. Série Zoologia, 94(4), 425–428.

Emmerson, W.D., & Alexander, M.D. (1986). Shell utilization and morphometries of the hermit crab *Diogenes brevirostris* Stimpson. African Zoology, 21(3), 211–216.

Fantucci, M.Z., Biagi, R., & Mantelatto, F.L. (2008). Shell occupation by the endemic western Atlantic hermit crab *Isocheles sawayai* (Diogenidae) from Caraguatatuba, Brazil. Brazilian Journal of Biology, 68(4), 859–867.

Fatima, M. (2007). Shell utilization by the hermit crab, *Diogenes planimanus* (Anomura: Diogenidae) from Karachi Coast, Pakistan. Pakistan Journal of Zoology, 39(4), 233–238.

Fotheringham, N. (1976). Population consequences of shell utilization by hermit crabs. Ecology, 57(3), 570–578.

Garcia, R.B., & Mantelatto, F.L. (2000). Variability of shell occupation by intertidal and infralittoral *Calcinus tibicen* (Anomura, Diogenidae) populations. Nauplius, 8(1), 99–105.

Garcia, R.B., & Mantelatto, F.L. (2001). Shell selection by the tropical hermit crab *Calcinus tibicen* (Herbst, 1791) (Anomura, Diogenidae) from Southern Brazil. Journal of Experimental Marine Biology and Ecology, 265(1), 1–14.

Hahn, D.R. (1998). Hermit crab shell use patterns: response to previous shell experience and to water flow. Journal of Experimental Marine Biology and Ecology, 228(1), 35–51.

Hazlett, B.A. (1981). The behavioral ecology of hermit crabs. Annual Review of Ecology and Systematics, 12(1), 1–22.

Ismail, T.G.E.K. (2010). Distribution and shell selection by two hermit crabs in different habitats on Egyptian Red Sea Coast. Acta Oecologica, 36(3), 314–324.

Jhala, D., Munjpara, S.B., Joshi, J., Joshi, K., & Chettiar, S.S. (2017). Spatial distribution of Intertidal hermit crab (Decapoda: Anomura) together with gastropod shell availability and utilization pattern on the southern coast of Gulf of Kachchh, Gujarat, India. Indian Journal of Life Sciences, 6(1), 77–85.

Kellogg, C.W. (1976). Gastropod shells: a potentially limiting resource for hermit crabs. Journal of experimental marine Biology and Ecology, 22(1), 101–111.

Manjón-Cabeza, M.E., & Raso, J.E. (1999). Shell utilization by the hermit crabs Diogenes pugilator (Roux, 1829), *Paguristes eremita* (Linnaeus, 1767) and *Pagurus forbesii* Bell, 1845 (Crustacea: Decapoda: Anomura), in a shallow-water community from Southern Spain. Bulletin of Marine Science, 65(2), 391–405.

Mantelatto, F.L.M., & Garcia, R.B. (2000). Shell utilization pattern of the hermit crab *Calcinus tibicen* (Diogenidae) from southern Brazil. Journal of Crustacean Biology, 20(3), 460–467.

McLaughlin, P.A., & Holthuis, L.B. (2001). In pursuit of JFW Herbst's species of *Diogenes* (Anomura: Paguridea: Diogenidae). Journal of Crustacean Biology, 21(1), 249–265.

Mutlu, E., & Ergev, M.B. (2010). Temporal variability of density and diverse shell occupancy of *Diogenes pugilator* on a sandy bottom of the Levantine Sea and their biometrical relationships. Cahiers de biologie marine, 51(1), 55–67.

Nardone, F., & Gherardi, F. (1997). The question of coexistence in hermit crabs: population ecology of a tropical intertidal assemblage. Crustaceana, 70(5), 608–629.

Orians, G.H., & King, C.E. (1964). Shell selection and invasion rates of some Pacific hermit crabs. Pacific Science, 18(3), 297–306.

Osorno, J.L., Fernandez-Casillas, L., & Rodrıiguez-Juarez, C. (1998). Are hermit crabs looking for light and large shells?: evidence from natural and field induced shell exchanges. Journal of Experimental Marine Biology and Ecology, 222(1-2), 163–173.

Patgaonkar, R.S., Vethamony, P., Lokesh, K.S., & Babu, M.T. (2012). Residence time of pollutants discharged in the Gulf of Kachchh, northwestern Arabian Sea. Marine pollution bulletin, 64(8), 1659–1666.

Pechenik, J.A., Hsieh, J., Owara, S., Wong, P., Marshall, D., Untersee, S., & Li, W. (2001). Factors selecting for avoidance of drilled shells by the hermit crab *Pagurus longicarpus*. Journal of Experimental Marine Biology and Ecology, 262(1), 75–89.

Rahayu, D.L. (2001). Hermit crabs from the South China Sea (Crustacea: Decapoda: Anomura: Diogenidae, Paguridae, Parapaguridae). Raffles Bulletin of Zoology, 48, 377–404.

Ragagnin, M.N., Gorman, D., McCarthy, I.D., Sant Anna, B.S., de Castro, C.C., & Turra, A. (2018). Gastropod shell size and architecture influence the applicability of methods used to estimate internal volume. Scientific reports, 8(1), 1-11.

Reese, E.S. (1969). Behavioral adaptations of intertidal hermit crabs. American Zoologist, 9(2), 343–355.

Rittschof, D., Sarrica, J., & Rubenstein, D. (1995). Shell dynamics and microhabitat selection by striped legged hermit crabs, *Clibanarius vittatus* (Bosc). Journal of Experimental Marine Biology and Ecology, 192(2), 157–172.

Sallam, W.S. (2012). Egg production and shell relationship of the land hermit crab *Coenobita scaevola* (Anomura: Coenobitidae) from Wadi El-Gemal, Red Sea, Egypt. The Journal of Basic & Applied Zoology, 65(2), 133–138.

Sant'Anna, B.S., Dominciano, L.C., Buozi, S.F., & Turra, A. (2012). Is shell partitioning between the hermit crabs *Pagurus brevidactylus* and *Pagurus criniticornis* explained by interference and/or exploitation competition?. Marine Biology Research, 8(7), 662–669.

Sant'Anna, B.S., Zangrande, C.M., Reigada, A.L., & Pinheiro, M.A. (2006). Shell utilization pattern of the hermit crab *Clibanarius vittatus* (Crustacea, Anomura) in an estuary at São Vicente, State of São Paulo, Brazil. Iheringia. Série Zoologia, 96(2), 261–266.

Scully, E.P. (1979). The effects of gastropod shell availability and habitat characteristics on shell utilization by the intertidal hermit crab *Pagurus longicarpus* Say. Journal of Experimental Marine Biology and Ecology, 37(2), 139–152.

Shih, H.T., & Mok, H.K. (2000). Utilization of shell resources by the hermit crabs *Calcinus latens* and *Calcinus gaimardii* at Kenting, southern Taiwan. Journal of Crustacean Biology, 20(4), 786–795.

Siddiqui, F.A., Kazmi, Q.B., & McLaughlin, P.A. (2004). Review of the Pakistani species of *Diogenes* Dana 1851 (Decapoda Anomura Paguroidea Diogenidae). Tropical Zoology, 17(2), 155–200.

Subba Rao, N.V., & Sastry, D.R.K. (2005). Fauna of Marine National Park, Gulf of Kachchh (Gujarat). An Overview. In: Director ZSI, Kolkata (Ed.), Conservation Area Series. Zoological Survey India, Kolkata, 23, 79 pp.

Taylor, P.R. (1981). Hermit crab fitness: the effect of shell condition and behavioral adaptations on environmental resistance. Journal of Experimental Marine Biology and Ecology, 52(2-3), 205–218.

Trivedi J.N., Gadhavi M.K., & Vachhrajani K.D. (2012). Diversity and habitat preference of brachyuran crabs in Gulf of Kutch, Gujarat, India.Arthropods, 1, 13–23.

Trivedi, D.J. Trivedi, J.N., Soni, G.M., Purohit, B.D., & Vachhrajani, K.D. (2015). Crustacean fauna of Gujarat state of India: A review. Electronic Journal of Environmental, 8, 23–31.

Trivedi, J.N., & Vachhrajani, K.D. (2014). Pattern of shell utilization in the hermit crab *Clibanarius zebra* (Dana, 1852) along the Saurashtra coast, Gujarat, India. Tropical zoology, 27(4), 129–139.

Trivedi, J.N., & Vachhrajani, K.D. (2017). An annotated checklist of hermit crabs (Crustacea, Decapoda, Anomura) of Indian waters with three new records. Journal of Asia-Pacific Biodiversity, 10(2), 175–182.

Turra, A., & Leite, F.P. (2000). Population biology and growth of three sympatric species of intertidal hermit crabs in south-eastern Brazil. Journal of the Marine Biological Association of the United Kingdom, 80(6), 1061–1069.

Turra, A., & Leite, F.P. (2002). Shell utilization patterns of a tropical intertidal hermit crab assemblage. Journal of the Marine Biological Association of the United Kingdom, 82(1), 97–107.

Turra, A., & Leite, F.P. (2003). The molding hypothesis: linking shell use with hermit crab growth, morphology, and shell-species selection. Marine Ecology Progress Series, 265, 155–163.

Vaghela, A., & Kundu, R. (2012). Spatiotemporal variations of hermit crab (crustacea: decapoda) inhabiting rocky shore along Saurashtra coast, western coast of India. Indian Journal of Geo-Marine Science, 41(2), 146–151.

Vance, R.R. (1972). Competition and mechanism of coexistence in three sympatric of intertidal hermit crabs. Ecology, 53(6), 1062–1074.

Vermeij, G.J. (1976). Interoceanic differences in vulnerability of shelled prey to crab predation. Nature, 260(5547), 135–136.

Wilber, T.P. (1989). Associations between gastropod shell characteristics and egg production in the hermit crab *Pagurus longicarpus*. Oecologia, 81(1), 6–15.