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Biodiversity and distribution of marine gastropods (Mollusca) during pre- and post-monsoon seasons along the Goa coastline, India

Anuradha David
UGC - Academic Staff College, Karnatak University, Dharwad - 580 003, Karnataka, India

*Correspondence e-mail: dmanuradha@gmail.com

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Original Article

Abstract

Biodiversity and distribution of different gastropod species was studied during pre- and post- monsoon seasons in sub-and inter-tidal zones from 16 sampling sites located in the northern and southern regions of the Goa coastline, India. Each site was surveyed twice during the pre-monsoon and twice in the post-monsoon season. A set of 2,493 specimens, 86 species, 51 genera, and 24 families were identified during the sixteen surveys that were conducted, four each in the pre- and post-monsoon season during January 2008 to September 2009. Species abundance was higher in rocky inter-tidal zones when compared with sandy and or sub-tidal zones. Shannon-Weiner biodiversity index (H') ranged from 2.1749 in the pre-monsoon season to 5.7641 during the post-monsoon months. Species richness (d) was the highest in Vacra and the lowest in Velsao during the pre- and post monsoon seasons. Peilou's indices recorded higher species evenness in the post-monsoon months in all the sampling sites. The highest number of species/individuals was obtained in Vacra (63/218) and the lowest in Miramar (13/74) respectively. A significant increase ($P<0.001$) was observed in the total number of individuals collected month wise in the pre- and post-monsoon seasons. Anjuna, Candolim, Sinquerim in north Goa and Betul, Palolem and Vacra in south Goa recorded more than 50 species whereas, less than 15 species were found in Dona Paula, Miramar (north Goa) and Velsao, Colva (south Goa). The highest number of individuals collected belonged to two families namely, Turritellidae and Trochidae. The results of this study indicate that the coasts of Goa are known to be a haven for gastropod fauna and needs to be protected to promote the conservation of this vulnerable resource.

Keywords: *Gastropoda, Mollusca, spatial distribution, tidal zones, seasonal variations.*

Introduction

India is one among 12 mega-biodiverse countries and 25 hotspots of the richest and highly endangered eco-regions of the world. Among the Asian countries, India is perhaps the only one that has a long record of inventories of coastal and marine biodiversity dating back to atleast two centuries. In terms of marine environment, India has a coastline of about 8000 km adjoining the continental regions and the offshore islands and a very wide range of coastal ecosystems such as estuaries, lagoons, mangroves, backwaters, salt marshes, rocky coasts, sandy stretches and coral reefs (Venkataraman, 2003; Venkataraman and Wafar, 2005).

Goa is located on the western coast of the Indian peninsula wedged between the Arabian Sea on one side and Western Ghats on the other (Mascarenhas, 1999; Mahadev *et al.*, 2004, Nagi, 2008). Goa encompasses an area of 3,702 km^2 (1,430 sq miles) (Nagi, 2008). It is located between latitudes 15° 48′ 00″ N and 14° 53′ 54″ N and longitudes 74° 20′ 13″ E and 73° 40′ 33″ E, is 1,022 meters above sea - level and

has a coastline of 101 km (63 miles) (Mahadev *et al.*, 2004; Nagi 2008). Goa experiences tropical weather for most of the year and temperatures vary between 19°C - 32°C (Mahadev *et al.*, 2004; Nagi 2008). The Southwest monsoon hits the state between June and September and July receives the highest rainfall (98 mm), while February is the driest month (Mascarenhas 1999; Mahadev *et al.*, 2004; Nagi, 2008).

The molluscs are soft bodied animals with a long evolutionary history and diversity (Chiba, 2007; Benkendorff and Przeslawski, 2008; Bogan, 2008). Considerably more is known about marine molluscs than most other invertebrate phyla, and they have been shown to be an appropriate indicator group for local invertebrate biodiversity (Smith, 2005; Smith *et al.,* 2008). Molluscs have been favoured in previous studies on rocky shores and inter-tidal zones because they are numerous, relatively slow moving and easy to identify (Benkendorff and Davis, 2002; Chiba, 2007; Benkendorff and Przeslawski, 2008). They are an important component of inter-tidal biota, with a unique combination of assets that make them readily studied. First, molluscan shells persist relatively intact for some time after the death of the animal, increasing the chances of sampling seasonal and rare species. Second, species identification is usually possible at any growth stage. And third, they are all visible and collectable with the naked eye (Emberton *et al.,* 1999; Chiba, 2007; Benkendorff and Przeslawski, 2008; Bogan, 2008).

According to Strong *et al.* (2008), the Western Ghats in India is known as the hot spot of gastropod diversity. However, there is virtually no information available on the current status of molluscan fauna along the Karnataka-Goa coastline, which forms a major geographical belt of the Western Ghats. Therefore, the present study was undertaken to (1) prepare a check list of the gastropod species that inhabit the inter-tidal and sub-tidal zones in sandy and rocky beaches of north and south Goa, (2) measure species diversity, richness and evenness using diversity indices (3) estimate seasonal variation of gastropod diversity in the inter-tidal and sub-tidal zones of sandy and rocky shores along the Goa coastline.

Material and methods

Study area and sampling sites

The study area that comprised the coastline in the state of Goa was divided into two regions: 1) North Goa (15° 48′ 00″ N to 14° 53′ 54″ N; 73° E to 75° E) and 2) South Goa (15° 29′ 32″ N to 14° 53′ 57″ N and 73° E to 74° E). Inter-tidal and sub-tidal zones were included in both regions along the coastline covering a distance of 100 kms. Of the 16 selected sampling sites, 8 were located in north Goa namely, Dona Paula, Sinquerim, Candolim, Calangute, Baga, Anjuna, Vagator and Miramir; while, the remaining eight sites that belonged to south Goa were Colva, Betul, Betalbatim Vacra, Galgibagh, Velsao, Majorda, and Palolem. The sampling sites consisted of six rocky beaches, three each namely, Anjuna, Candolim and Sinquerim in north Goa and Betul, Palolem and Vacra in south Goa respectively, the remaining 10 sites were sandy beaches. While selecting the sampling sites, their proximity to industries, harbour and human habitation was considered. Sites more than 30 kms away from the city and in seclusion were also included in this investigation. This was done in order to ensure equal representation of gastropod fauna in various habitats.

Field sampling, processing and identification of specimens

The Benkendorff and Davis (2002) methodology for survey and collection of specimens was followed in this study. Extensive surveys for live and dead gastropods were conducted in the inter-tidal and sub-tidal zones in rocky and sandy shore during the pre-monsoon and post-monsoon seasons at all the 16 sampling sites. The surveys were undertaken at low tide in clear weather and relatively calm sea conditions between January 2008 and September 2009. Each sampling site area was visited once in January, February, March and April during the pre-monsoon season and once again in June, July, August and September during post-monsoon season. A timed 2-4 hours search survey was conducted at each site during the eight months and a species list of molluscs was generated for each survey. Molluscan species were collected (handpicked by the author along with the assistance of local fishermen) across the entire range of habitats at all levels of the shore. In particular, attention was paid to the undersides of boulders, both in dry regions and in water-retaining crevices and hollows. Other rocky surfaces, such as vertical rock faces, caves and crevices, were searched extensively for specimens. The tidal pools on rock platforms were also examined. A uniform depth range of 0.1 - 0.2 M was maintained for both rocky and sandy zones in surveys conducted in fine and rainy weather. In all surveys live specimens were not disturbed from their habitats, however their images were captured using a NIKON D60 digital SLR camera and specimens subsequently identified using identification keys.

After collection, the specimens from each site were transported in large plastic bags that were numbered sequentially with a codename for each sampling site. Soon after arrival in the lab, the shells were soaked for 30 minutes in glass aquaria containing warm water mixed with a mild detergent to get rid of mucous/debris and odor, following which they were rinsed several times in tap water and dried in shade for a week. After ensuring that no water content remained on the internal

and external surfaces of the specimens, they were sorted and stored in plastic sachets.

Shelled gastropods collected were identified according to keys of Apte (1998) and Dance (2002). Where the discrepancies or difference in species names between these two publications arose, the nomenclature of Dance (2002) was used.

Data analysis

Biodiversity can be quantified in many different ways. The two main factors taken into account when measuring diversity are species richness and evenness. The following biodiversity indices were calculated for the data:
(1) Shannon-Weiner (H') Index to characterize gastropod diversity and expressed as $H' = \sum (pi \ln pi)$ where, S = total number of species collected, and pi = proportion of individuals in sample that belong to species 'I'.
(2) Margalef Index (d) to estimate species richness given by S-1/ln N, where S is the number of species and N is the number of individuals.
(3) Pielou's (J) index to determine species evenness was expressed as H'/ln S, where, H' = Shannon-Weiner index, and S = total number of species encountered.

Data collected were subjected to statistical analysis using Analysis of Variance (1-way ANOVA) to determine the month-wise occurrence in the total number of individuals (N) of gastropods before and after monsoon season (Zar 1984; Forthofer *et al.,* 2007). Paired "T" test was done to compare the difference in the total number of individuals collected before and after the monsoon season. Wilcoxon signed ranked test (Z) was used to compare means for each individual species (Zar, 1984; Forthofer *et al.,* 2007). Data were analyzed using SPSS (ver. 13.0) software.

Results

Spatial distribution of species

A total of 2493 specimens, 86 species, 51 genera, and 24 families were collected over the entire study area consisting of 16 sampling sites in the northern and southern regions (Figs 1 and 2, Table 1). Cumulative records of sampled individuals during sixteen surveys of which four each were undertaken during the pre-monsoon and post monsoon seasons of the study period revealed that a set of 51 species, 93 genera, and 28 families was found exclusively in the inter-tidal zone of rocky beaches, whereas 35 species, 43 genera, and 14 families were exclusive to the sub-tidal zone of sandy beaches. Only 16 species (18.6%), 10 genera (22.7%), and 6 families (24.9%) occurred in both zones.

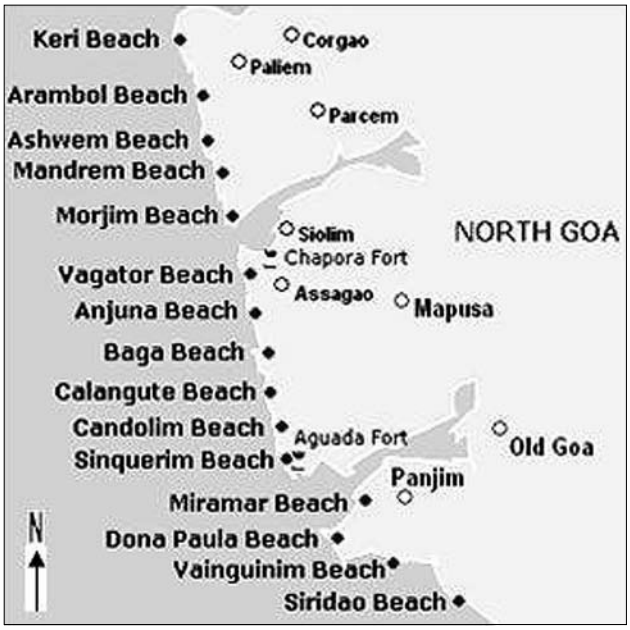

Fig. 1. Map of north Goa

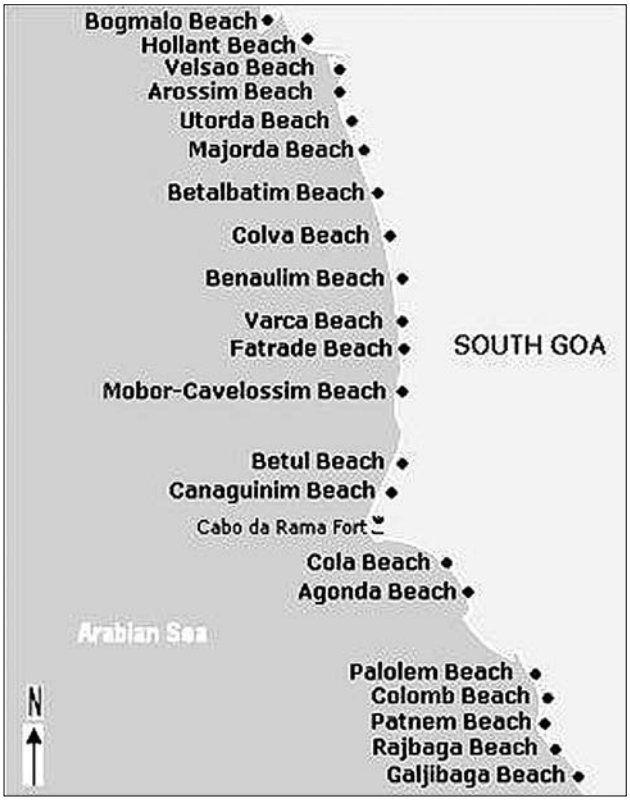

Fig. 2. Map of south Goa

Anjuna, Candolim and Sinquerim in north Goa and Betul, Palolem and Vacra in south Goa recorded more than 50 species during the study period (Figs. 1, 2 and 3). More than 200 individuals were collected from 4 sampling sites, during the study period namely Anjuna and Sinquerim of north Goa,

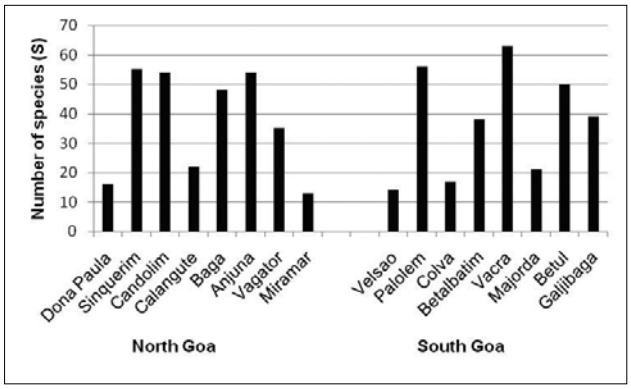

Fig. 3.Total number of species (S) collected from each sampling site

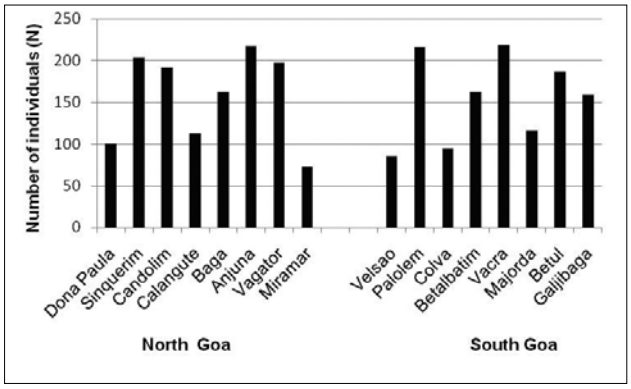

Fig. 4.Total number of individuals (N) collected from each sampling site

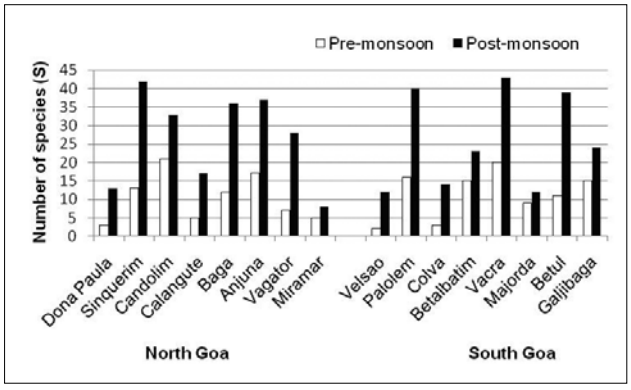

Fig. 5. Seasonal variation in species occurrence

Palolem and Vacra of south Goa (Figs. 1, 2 and 4). Candolim in north Goa and Vacra in south Goa recorded the highest number of species during the pre and post-monsoon seasons (Figs. 1, 2 and 5). Miramar, Dona Paula in north Goa and Velsao, Colva in south Goa showed the lowest number of species and individuals during the study period (Figs. 1- 4).

Gastropod diversity

Diversity indices for the sampling sites are shown in Tables 2 and 4. Data revealed that during the pre-monsoon months

Table 1. Taxonomic list of species sampled from inter-tidal and sub-tidal zones

Super Family	Family	Species
Cerethoidea	Cerithiidae	*Clypeomorus bifasciata* G.B.Sowerby, 1855
		Rhinoclavis sinensis Gmelin, 1791
		Cerithium echinatum Lamarck, 1822
		Cerithidea scalariformis, Say, 1825
	Planaxidae	*Planaxis acutus*, Menke, 1851
		Planaxis lineatus, Da Costa, 1778
		Planaxis similis Smith, 1872
		Planaxis sulcatus Born, 1778
	Potamididae	*Potamides cingulatus* Gmelin, 1791
		Telescopium telescopium Linnaeus, 1758
	Turritellidae	*Turritella duplicata* Linnaeus, 1758
		Turritella terebra cercea Reeve, 1843
		Turritella terebra Linnaeus, 1758
Littorinoidea	Littorinidae	*Littorina intermedia* Philippi, 1846
		Littorina lineolata D'Orbigny, 1840
		Littorina scabra Linne, 1758
Naticoidea	Naticidae	*Eunaticina papilla* Gmelin, 1791
		Natica maculosa Lamarck, 1822
		Natica picta Recluz, 1844
		Notocochlis tigrina Röding, 1798
Neritoidea	Neritidae	*Nerita albicilla* Linnaeus, 1758
		Nerita crepidularia Lamarck, 1822
		Nerita oryzarum Récluz, 1841
Patelloidea	Patellidae	*Cellana radiate* Born, 1778
		Clypidina notata Linnaeus, 1785
Trochoidea	Trochidae	*Callostoma euglyptum* A. Adams, 1855
		Clanculus ceylonicus G. & H. Nevill, 1869
		Euchelus asper Gmelin, 1791
		Euchelus tricarinata Lamarck, 1758
		Isanda crenulifera A. Adams, 1854
		Trochus radiatus Gmelin, 1791
		Trochus tentorium Gmelin, 1791
		Trochus maculatus Linnaeus, 1758
		Tegula eiseni Jordan, 1936
		Umbonium vestiarium Linnaeus, 1758
	Turbinidae	*Astralium semicostatum* Kiener, 1850
		Astraea stellata Gmelin, 1791
		Lithopoma sp
		Margarites costalis Gould, 1841
		Margarites groenlandicus Gmelin, 1791
		Turbo bruneus Röding, 1798
		Lunella coronata Gmelin, 1791
Cypraeoidea	Cypraeidae	*Procalpurnus lacteus* Lamarck, 1810
		Erosaria ocellata Linnaeus, 1758

		Erosaria inocellata Gray, 1825
		Erosaria lamarckii J. E. Gray, 1825
		Paulonaria fimbriata Schroeter, 1825
		Staphylaea staphylaea Linnaeus, 1758
Patelloidea	Patellidae	*Collisella leucopleura* Linne, 1758
		Lottia strigatella Carpenter, 1864
		Notoacmaea antillarum Sowerby, 1831
Pyramidelloidea	Pyramidellidae	*Pyramidella dolabrata* Linnaeus, 1758
Tonnoidea	Ranellidae	*Gyrineum pusillum* Broderip, 1833
Conoidea	Conidae	*Conus textile* Linnaeus, 1758
		Conus erythraeensis dillwynii Reeve, 1849
		Conus tessulatus Born, 1778
	Turridae	*Clarus crassa* Smith, 1853
		Surcula amicta Smith, 1877
		Surcula fulminata Kiener, 1839
		Surcula javana Linnaeus, 1758
Epitonoidea	Epitoniidae	*Amaea minor* Sowerby II, 1873
Muricoidea	Buccinidae	*Babylonia spirata* Linnaeus, 1758
		Babylonia zeylanica Bruguière, 1789
		Pollia undosa Linnaeus, 1758
		Engina zea Melvill, 1893
		Lophiotoma indica Röding, 1798
	Columbellidae	*Pyrene terpsichore* Sowerby, 1822
	Margininellidae	*Cryptospira strigata* Dillwyn, 1817
		Volvarina angustata G.B. Sowerby II, 1846
	Mitridae	*Vexillum obeliscus* Reeve, 1844
		Mitra scutulata Gmelin, 1791
	Muricidae	*Drupa konkanensis* Melvill, 1893
		Drupa Reeve, 1846
		Nassa francolina Bruguière, 1789
		Nassa francolina Bruguière, 1789
		Indothais lacera Born, 1778
		Purpura persica Linnaeus, 1758
		Thais sacellum Gmelin, 1791
		Semiricinula tissoti Petit dela Saussaye, 1852
	Nassariidae	*Bullia mauritiana* Gray, 1839
		Ilyanassa obsoleta Say, 1822
		Nassarius mendicus Gould, 1850
		Nassarius distortus A. Adams, 1852
		Nassarius vibex Say, 1822
	Olividae	*Oliva caerulea* Röding, 1798
		Agaronia plicaria Lamarck, 1811

the H' values ranged from 2.1749 to 5.436 (Table 2). Species richness (d) was found to be the highest in Vacra and lowest in Velsao, while Peilou's evenness index was least at Sinquerim and highest at Betalbatim and Betul (Table 2). The H' values ranged from 2.558 (Dona Paula) to 5.7653 (Majorda) in the post-monsoon season (Table 3). Margalef's index for richness was highest in Vacra and lowest in Velsao during the post-monsoon period; Dona Paula, Velsao, Colva and Majorda showed maximum evenness after the monsoon season (Table 3).

Seasonal variations

In the pre-monsoon season, the number of species recorded in Dona Paula, Miramar, Velsao, Colva and Calangute were less than or equal to 5 (Fig. 5, Table 2). It was observed that at five sampling sites namely, Dona Paula, Miramar, Velsao, Colva and Majorda recorded less than or equal to 15 species after the monsoon season (Fig. 5, Table 3). A set of 102 individuals belonging to 16 species was sampled from Palolem during the pre-monsoon season (Table 2). About 55 and 98 individuals from as many as 21 and 20 species each were collected from Candolim and Vacra respectively (Table 2). In the post-monsoon season, 155 individuals belonging to 37 species were collected from Anjuna, while, 120 from 43 species in Vacra and 112 from 42 species were found in Sinquerim (Table 3).

The month-wise data for seasonal variations in gastropod species showed a gradual decrease ($P<0.01$) in the total number of individuals during the four pre-monsoon months (Table 4). Likewise, a significant ($P<0.01$) increase was observed in June and July, the first two months of the post monsoon season (Table 4). However, there was a significant ($P<0.01$) decrease in the total number of individuals in the post monsoon months of August and September (Table 4).

Discussion

A number of studies have been conducted on various biological aspects of molluscs, along with biodiversity and distribution patterns (Lowry *et al.,* 1974; Suzuki *et al.,* 2002; Watson and Ormerod 2004; Smith 2005; Schrodl et al. 2006; Selin and Latypov 2006; Sitnikova 2006; Rawlings *et al.,* 2007; Zamorano *et al.,* 2007; Strong *et al.,* 2008; Benkendorfer and Gomes 2009), topographical complexity, genetic and species diversity (Sinclaire *et al.,* 2007; Pinn *et al.,* 2008; Rosa *et al.,* 2008) seasonal variation (Rueda and Salas 2008) speciation, molecular phylogeny, ecology and biogeography (Williams and Reid 2004; Yu and Chu 2006; Zamorano *et al.,* 2007; Rundell 2008).

This preliminary investigation was undertaken to study the biodiversity and distribution of gastropod fauna along the Goa coastline during the wet monsoon and dry summer

seasons. The surveys that were conducted on 16 carefully selected sampling sites comprising of rocky and sandy sub-tidal and inter-tidal zones revealed more than 80 species of gastropods that inhabit the coastal belt of Goa in India. Species richness was prominent mainly in rocky inter-tidal or littoral zones as reported for similar zones in south-eastern Australia (Benkendorff and Davis, 2002). The sites with the highest richness were Vacra, Sinquerim, Palolem and Candolim during the pre and post-monsoon seasons (Figs. 3-5). This may be due to rough terrain of these sites consisting of sharp rocky edges, steep cliffs and creeks that prevents disturbances due to anthropogenic interferences. Sub-tidal zones of all sandy beaches in north and south Goa beaches were low in species richness and total number of individuals owing to the extensive exploitation of these ecosystems for tourism and related urbanization (Figs. 3-4). Dona Paula and Velsao show poor species richness and lower number of specimens since these two sites lie close to the Mormugao harbour from where large amounts of toxic waste materials from shipping activities are released resulting in high contamination of these water bodies (Sarkar *et al.,* 2008).

A striking result of this study indicates a significant increase in the total number of species and individuals in the post-monsoon season (Figs. 3-5; Tables 4). The cause for this variation whether related to the change in the temperature or other environmental factors remains to be studied. The question as to whether these are rare or endemic species requires further experimentation. Some of the difficulties that were confronted during the study period included incessant rain during the monsoon season, occurrence of live specimens at the time of collection, excessive human activity (tourism and construction) at sampling sites (Colva, Baga, Vagator, Miramar) hampered the sampling process and thereby did not permit proper representation of gastropod fauna.

The coastal zone of Goa has been exclusively used for agriculture, farming, shell fishing, traditional fishing and low-key recreation. Native Goans used the shoreline and the hinterland water bodies to fish by using hand-cast and hand-pulled nets, gather shells for economic and various other purposes (Mascarenhas, 1999). A rapid increase in urbanization and tourism seems to have affected the biodiversity and distribution of gastropod fauna in this region.

In conclusion, this is the first preliminary report on the occurrence, number of species and their distribution including seasonal variations of marine gastropods in the Goa coast. Inter-tidal zones are known to support a wide variety of fauna (Benkendorff and Davis, 2002; that needs to be protected and preserved. In this direction, more comprehensive studies and extensive seasonal sampling surveys have to be undertaken to assess the precise diversity and distribution patterns of marine gastropods.

Table 2. Diversity indices during pre-monsoon months

Sampling sites	N	S	H′	d	J
Dona Paula	27	03	2.5443	2.1530	0.9177
Sinquerim	91	13	3.2571	2.6023	0.9128
Candolim	55	21	3.296	3.2811	0.9263
Calangute	48	05	2.6169	2.6621	0.9466
Baga	39	12	3.1892	3.8319	0.9238
Anjuna	62	17	3.4186	3.9742	0.957
Vagator	82	07	3.048	3.2234	0.9573
Miramar	30	05	2.1749	0.8824	0.9595
Velsao	21	02	2.4134	0.5412	0.9145
Palolem	102	16	3.5205	4.3825	0.9746
Colva	25	03	2.5937	2.9122	0.9155
Betalbatim	77	15	3.8291	3.3709	1
Vacra	98	20	3.7843	4.4278	0.9134
Majorda	51	09	2.3919	2.3949	0.9856
Betul	82	11	5.436	3.7091	1
Galjibaga	69	15	3.0963	3.3237	0.9452

N – Number of individuals (at each sampling site) S – Number of species (at each sampling site) H′ – Shannon-Weiner (Biodiversity) Index d – Margalef (Species richness) index J – Pielou (Species evenness) index

Table 3. Diversity indices during post-monsoon months

Sampling sites	N	S	H'	d	J
Dona Paula	73	13	2.558	2.7151	1
Sinquerim	112	42	3.2847	3.2067	0.9219
Candolim	136	33	3.6652	3.3657	0.9312
Calangute	62	17	3.0082	2.7364	0.9564
Baga	124	36	3.5673	3.9997	0.9307
Anjuna	155	37	4.1211	4.3353	0.9902
Vagator	115	28	3.3567	3.288	0.9615
Miramar	44	08	2.6893	1.1929	0.9346
Velsao	64	12	3.2246	1.1325	1
Palolem	114	40	4.6483	4.1838	0.9798
Colva	69	14	3.0836	2.6898	1
Betalbatim	86	23	4.0187	3.9997	1.9534
Vacra	120	43	5.2116	4.4866	0.9276
Majorda	65	12	2.7653	2.4026	1
Betul	105	39	5.7641	3.7478	0.9802
Galjibaga	90	24	3.8312	3.3678	0.9313

N – Number of individuals (at each sampling site) S – Number of species (at each sampling site) H' – Shannon-Weiner (Biodiversity) Index d – Margalef (Species richness) index J – Pielou (Species evenness) index

Table 4. Month wise seasonal variation in the total number of individuals (N)

	Pre-monsoon			Post- monsoon		F - value
	2008	2009		2008	2009	
Jan	1.89 ± 0.51	1.85 ± 0.40	Jun	5.20 ± 0.82 a	6.13 ± 0.33 b	11.706*
Feb	1.50 ± 0.44	1.53 ± 0.11	Jul	6.59 ± 1.04 a	6.09 ± 0.61b	20.121*
Mar	1.09 ± 0.32	1.00 ± 0.69	Aug	6.16 ± 1.27 a	5.97 ± 0.49 b	21.121*
Apr	0.65 ± 0.20	0.72 ± 0.19	Sep	5.28 ± 0.95 a	5.81± 0.39 b	22.744*

Values are means ± standard errors; * Significant at 1% level; df = 1,
a Significant (P<0.01) compared with pre-monsoon group of 2008
b Significant (P<0.01) compared with pre-monsoon group of 2009

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