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RESEARCH ARTICLE

Diversity, distribution and checklist of brachyuran crabs inhabiting along the Mumbai and Konkan coast of Maharashtra, India

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ABSTRACT

The present paper includes a diversity of brachyuran crabs inhabiting along intertidal and shallow subtidal regions of Mumbai and Konkan coasts of Maharashtra, India. During a survey from 2014 to 2016, a total of 55 species of crabs, belonging to 45 genera and 22 families, were recorded from these areas. According to the Shannon Weiner index (H'), the maximum diversity was recorded around Mumbai rocky shores, having mixed types of microhabitats. The values of Shannon-Weiner index (H') varied between 2.3 and 3.0 for Mumbai as well as Jaitapur, whereas, evenness varied between 0.86 and 0.97, while richness fluctuated between 3.2 and 5.9. Seasonal observations revealed maximum diversity in pre monsoon and post monsoon at Marine Drive shore. The present study also reports total 10 species with 4 new records from intertidal regions of west coast of India (*Xenophthalmus wolfii, Ozius rugulosus, Achaeus cf spinosus, Leptodius cf sanguines*); 5 new distributional records for Maharashtra state (*Ozius tuberculosus, Ocypode brevicornis, Atergatis laevigatus, Pilumnopeus convexsus, Scylla olivacea*); and 1 first record of genus from Indian Ocean (*Anomalifrons garthii*). The results of present study can be used as baseline data for conservation and management of these ecologically sensitive fauna.

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Introduction

The intertidal areas are the boundary between marine and terrestrial habitats, which are subjected to variable degrees of physical factors and biological processes (Nybakken, 1993; Bertness, 1999), and their interactions determine the spatial and temporal patterns of biological resources on rocky shores (Terlizzi et al., 2002). Even though occupied almost entirely by

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marine organisms, they are regularly visited by shorebirds and even passerines that feed on intertidal animals. The crabs are common and ecologically important predators in benthic marine ecosystems. Most of the crabs feed on detritus or organic matter and play role in marine food web as prey or predator thus maintaining the ecosystem functions, in addition; they serve as an important food source livelihood for coastal communities. They are abundant in the rocky intertidal area which provides a unique habitat for them to hide under the rocks and burry in the sand and mud holes. The rocky intertidal zone serves as a natural laboratory for elucidating the role of physical and biological factors in determining the abundance and distribution of organisms in nature (Tomanek & Helmuth, 2002).

The brachyuran species assemblage in intertidal habitats of the west coast of India have been poorly studied until Fabricius (1775) reported first brachyuran crab from west coast of India. After a gap of 60 years, Milne Edwards (1852) reported 6 species from Bombay coast. Thus, studies on brachyuran fauna of Indian seas were initiated by Milne Edwards (1834) and de Man (1887) but confined to the investigations of species inhabiting the deep seas. However, the first consolidated work on brachyuran crabs from west coast of India was published by Pillai (1951), who described 51 marine and estuarine species from Travancore coast (now Kerala coast). Along Maharashtra coast, the first work on shallow water intertidal regions was published by Chhapgar (1957) who described 81 species. Thereafter, Sankolli & Shenoy (1975) reported one majid crab from Ratnagiri district of Maharashtra, followed report of three new records of portunid crabs from Maharashtra coast by Aravindakshan & Karbhari (1985). Subsequently, Khot et al. (2016) reported a brachyuran crab for first time from Maharashtra coast and established the relationship between carapace length and weight (Khot & Jaiswar, 2018). A perusal of literature on crabs from intertidal regions of west coast of Maharashtra is confined to Chhapgar (1957). In recent times, the aquatic biodiversity, including crustaceans, is affected. The brachyuran crabs, being benthic feeders, are most affected. Thus, there is need to assess the status of this group of animals. Since, Maharashtra is most industrialized state, it has become essential to assess the present status of marine crabs from the state. Further, there is lack of record on brachyuran crab diversity after Chhapgar who reported crabs from Maharashtra in 1991. Thus, the understanding of the status of crab diversity in intertidal regions is important where anthropogenic pressure is ever increasing in the sea. Thereafter, no data are available on documentation or taxonomy of brachyuran crabs from Maharashtra. Therefore, the understanding of the status of crab diversity in intertidal regions is important where anthropogenic pressure is ever increasing in the sea.

Material and Methods

Study Area

The intertidal areas from Mumbai were Marine Drive (MD), Girgaon Chowpatty (GR), Bandstand (BA), and Uttan (UT) whereas Ganeshgule (GG) and Ambolgad (AM) from Ratnagiri; and Girye (GI) and Devgad (DV) from Sindhudurg districts were selected for the study (Figure 1). Ratnagiri and Sindhudurg district fall in Konkan region and separated by 250 km from Mumbai region. From Mumbai region, four locations were selected, whereas two locations each from Ratnagiri and Sindhudurg district were chosen to compare the variation in fauna due to anthropogenic extent.

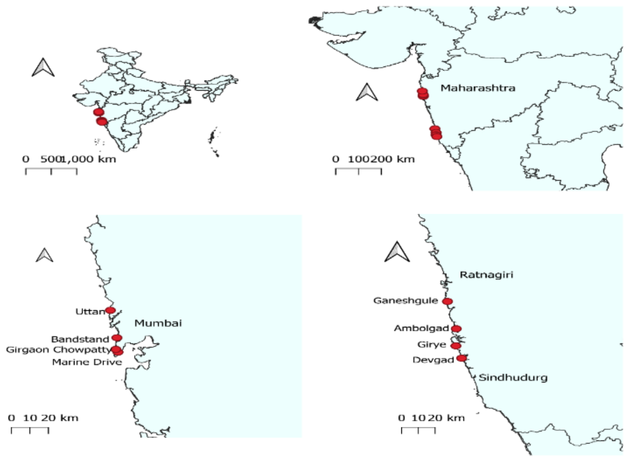

Figure 1. Study area

Habitat: Intertidal areas of Mumbai

Marine Drive

The Marine Drive (18.94°N, 72.82°E), a part of Queen's Necklace area, is three km long rocky shore which ends at Girgaon Chowpatty. The substratum of the shore is rocky with a few sandy patches and tidal pools. The upper intertidal area is artificially reclaimed with large size cement blocks and a road wall is constructed to avoid erosion of the shore, where gastropods are abundant due to lush growth of algae. The middle part of the shore is comprised of coral boulders, stones with sponges, debris like bricks and concrete structures and can be called as Zoanthus with algae & sponge zone. The lower zone, with flat rocks and boulders, is covered with Zoanthus, patches of corals, algae, gorgoniids etc. Originally the shore was sandy, but today, it is entirely changed, much similar to the rocky shore. The rocks are covered with silt-mud discharged from municipality pipelines. The area harbours different types of algae, sponges, molluscs, crabs, corals, zooanthids, brittlestar, etc. The area is attraction for tourists for its scenic beauty. Thus, the upper intertidal area is highly disturbed due to tourist activities while mid and low tidal zones are less affected and harbour rich biological diversity.

Girgaon Chowpatty

The shore, popularly known as Girgaon Chowpatty (18.95°N, 72.81°E), is part of the Queen's Necklace area 3km from Marine Drive. The upper intertidal area is covered with coarse sand and packed with food stalls. The middle intertidal area is covered with silty-muddy, while lower intertidal area is covered with mixed substratum of sandy-muddy and silt nature. Large number of people visit here every day, which is the cause for poor ecological conditions of the shore. The shore area is gently sloping and more than 500 m is exposed during spring low tide (at 0.06 m).

Bandstand

It is an open type of natural rocky shore (19.04°N, 72.81°E), composed of rock beds and stones of various dimensions, about 15km away from Marine Drive. It is also subjected to direct wave action throughout the year. Maximum exposure was recorded to be 198 m during spring low tide (0.03 m). Shore profile is very uneven. The upper intertidal zone is covered with conglomerate rocks harbouring barnacles and oyster. Middle zone is rich in gastropod and patchy coral zone, while lower zone is represented by gastropod-algal zone. The shallow tidal pools covered mostly with algae and gorgoniids, rocky crevices, under rocks, coral boulders, cobbles and boulders with algae is the characteristics of the area.

Uttan

It is situated towards the northern end of Mumbai (19.26°N, 72.81°E), approx. 54 km from Marine Drive. Many small and large drainage channels discharge effluents into it. The upper intertidal zone is covered with coarse sand, mid intertidal zone is covered with silt and mud, while the lower intertidal zone is covered with big flat conglomerate rocks and small pebbles. The habitat recorded here are rocks, rocky crevices, boulders with algae, shallow tidal pool with algae, along with sandy, sandy-muddy and silty-muddy patches. Maximum exposure was recorded to be 0.12 m during low tide.

Habitat: Intertidal areas from Ratnagiri district

Ganeshgule

It is a small and cleaner beach (16.87°N, 73.29°E) with a small village, situated 25 kms away from Ratnagiri town. The total beach area is 1.5 km, covered with white sand in upper, middle and lower intertidal zone. One end the beach is covered with rock patch while on other end a channel discharges freshwater during monsoon. The upper intertidal zone is occupied by medium and larger laterite and conglomerate rocks covered with barnacles, algae, anemones & gastropods; middle intertidal zone with *Sabellaria* reefs and lower zone with zoanthids. The habitat is comprised of under rocks, rocky crevices, shallow tidal pools with zooanthids, cobbles & boulders with algae, shallow tidal pools with algae. Local women collect bivalves for food during low tides.

Ambolgad

The small beach (16.64° N, 73.33° E), spread in a length of 1km, is separated by a distance of 5 km from Jaitapur and 55 km from Ratnagiri. The sandy beach is divided in to three zones *viz.* upper intertidal zone with white sand, middle zone with mixture of brown sand and clay with black layer of organic deposits providing suitable habitat for dotillids, and lower intertidal zone with brown fine sand with suitable habitat for starfishes. The rocky patch on the shore is further divided in to upper intertidal zone with large conglomerate and laterite rocks covered with oysters and can be called as oyster zone, middle zone is covered with medium size rocks covered with small gastropods, a gastropod zone; while lower zone is covered with shallow tidal pools with zoanthids.

Habitat: Intertidal areas from Sindhudurg district

Girye

The shore is situated near a small town Girye (16.56°N, 73.22°E), at a distance of 10 km from Jaitapur under Sindhudurg district. The beach covers an area of 2.5 km. At one end, the sandy zone area of about 2 km in length, having white sand in upper, middle and lower intertidal zone and the rocky patch covers an area of about approximately 800 m, where upper intertidal zone is occupied by white sand inhabited by *Ocypode* spp, the middle zone possesses few cobbles & grapsid crabs, while the lower intertidal zone is occupied by Zoanthus and coral reef zone. Fishing is carried out by locals for xanthid crabs, cowries, and bivalves for food.

Devgad

It is a town (16.37°N, 73.38°E) situated at 30 km distance from Jaitapur under Sindhudurg district. The sandy area covers about 1.5 km, upper intertidal zone having white sand, middle zone with ocypodid crabs and lower zone with fine brown sand. At other end the rocky patch is spread in an area of about approximately 500 m. The habitat in these zones are conglomerate rocks with barnacles, gastropods, algae & anemones, shallow tidal pools with algae, cobbles & boulders with algae, rocky crevices, under rocks, tidal pools with coral boulders and under rocks.

Sampling and Identification

Monthly sampling of crabs was carried out from intertidal areas around Mumbai and Jaitapur during 2014-2016 by following quadrate method, (NaGISA, 2006) protocol version II and handpicking using traps and forceps. Burrowing crabs were collected by digging the burrow. Random sampling was done by using the quadrate method. Three quadrates, covering an area of 1m^2 each, were fixed in high, mid and low tide level during spring low tide. The number of each species of crabs present in 1m^2 quadrates area was counted. At each quadrate, crabs were recorded by turning over the stones and small boulders and subsequently by putting back to their original position. The density of each species was expressed as average no/m^2. The abundance was calculated as total number of individuals of species present in given area and categorised as Abundant, Common, Frequent, Occasional and Rare. Specimens were also collected from local fishermen operating nets in the certain areas. At each site, local fishermen used hand net, gill net. Field photographs, habitat and human pressure were also recorded during collection. Representative specimens were stored in icebox immediately to avoid shedding of legs or chelae. The specimens were bought to laboratory and washed with tap water to remove mud, adhering sand and silt.

Taxonomic surveys, for assessing the crustacean assemblages, were performed at eight selected sites, representing different type of habitats. The collected crabs were identified by using standard identification key (Ng, 1998) "The living marine resources of the Western Central Pacific" Vol. 2; Chhapgar (1957); Sethuramalingam & Ajmal Khan (1991); NIO database on Marine life of India, Volume 2 "Marine crabs of India"; Jeyabaskaran et al. (2002); CD on Brachyuran Crabs of West Coast, India, at http://www.nio.org/Biology/brachyuran/index.html; Marine species identification portal (www.speciesidentification.org); research papers and monographs. The latest classification and scientific names of the species were adopted from Ng et al. (2008); website of www.sealifebase.com and WORMS (https://www.marinespecies.org/). Identification of crabs up to species level was done by observing the general characters such as carapace shape, chelipeds, ambulatory legs, anterolateral margins, frontal margins, maxillipeds, and pair of two pleopods. The first male pleopod was used as main character to distinguish between closely related species (Sankarankutty, 1962).

Identified specimens were photographed using Canon SX520HS for bigger size body parts, while for smaller parts and gonopods, Stereo microscope (Olympus, SZX16) was used. Morphometric details such as carapace length, carapace width, weight and sex were noted for each specimen. Representative specimens were then preserved in 70% alcohol and deposited in ICAR-Central Institute of Fisheries Education and Bombay Natural History Society (BNHS) Mumbai, India with appropriate labelling. Water parameters, such as pH, temperature and salinity, of the collection areas were analysed as per APHA (1998). The analysis of Pearson's correlation between different environmental variables was performed using software STATISTICA, ver.7.

Diversity

Univariate and multivariate analyses of brachyuran abundance data were carried out using the statistical software, PRIMER v6, developed by Plymouth laboratory U.K. The univariate techniques computed were Shannon–Wiener diversity index ($H'_{\log 2}$); Margalef's richness index (d), and Pielou's evenness index (J'). Multivariate analyses included the ordination of fourth root transformed data using Bray–Curtis similarities by non-metric multi-dimensional scaling (MDS). Graphical representations like k-dominance curve, was figured based on fourth root of transformed data, and cluster analysis was performed to discern similarities between sampling stations. The value of Shannon and Weiner diversity index increased with increase in richness and evenness. It will be zero if the sample in consideration has only one species and would be maximal when all species of the sample, in consideration, have even abundances (Sagar & Singh, 1999). K-dominance plot is also known as 'ranked species abundance plot' which measures the quantity of each taxon computed for abundance, biomass, % cover or other biotic measures. The Abundance and Biomass curve (ABC) indicates undisturbed community, if biomass curve is above the abundance curve; gross disturbance if abundance curve lies above biomass curve and moderate disturbance if the two lines intersect (Clarke & Warwick, 2001). A 'W' value measures the extent to which the biomass curve lies above the abundance curve (Clarke & Gorley, 2006). The taxonomic diversity index indicates average taxonomic distance between any two individuals chosen at random, provided they belong to two different species (Warwick & Clarke, 1995). The taxonomic distinctness index is the average path length between any two individuals chosen at random, provided they belong to two different species.

Results

Physicochemical Parameters

The values of salinity varied from 33.7 ppt (BA) to 35.1 ppt (UT) at the sites around Mumbai, and 30.1 ppt (AM) to 35.5 ppt (DV) around Jaitapur with maximum in pre monsoon. pH was found to vary from 7.9 (MD, GR, BA) to 8.2 (UT) around sites of Mumbai and 7.9 (AM) to 8.3 (DV) around sites of Jaitapur, with maximum in post monsoon and minimum in monsoon. The water temperature varied from 27.5°C to 28.9°C around Mumbai and 25.7°C to 30.5°C around Jaitapur.

Distribution and Species Composition

During the present study, a total of 55 species of crabs, belonging to 45 genera under 22 families, were recorded around Mumbai and Jaitapur (Table 1). The study also revealed a significant correlation between density of crabs and salinity (Table 2). Out of 55 species, 48 species were recorded from Mumbai area and 24 species from Jaitapur, where 17 species belonging to 9 families were common in both areas. The average density of crabs ranged from 2 to 5 ind/m^2 and 3 to 4 ind/m^2 around Mumbai and Jaitapur coasts, whereas biomass ranged from 28.6 to 180 g/m^2 and 78.69 to 152.66 g/m^2, respectively. The population density was high during pre-monsoon and post-monsoon; wherein, maximum density was recorded at Girgaon Chowpatty followed by Uttan beach, Bandstand and Marine Drive around Mumbai locations, and Devgad and Ganeshgule around Jaitapur coast. Maximum number of species was recorded from Marine Drive (26) followed by Girgaon Chowpatty (19), Uttan (17), Devgad (16), Ganeshgule (14) Bandstand, Ambolgad and Girye (13) site. Family wise percentage composition revealed maximum species under Portunidae followed by Xanthidae and Pilumnidae around Mumbai, whereas around Jaitapur, maximum species were recorded under Portunidae followed by Epialtidae and Calappidae (Figure 2). More number of families and species were recorded from Mumbai (48 species belonging to 21 families) than Jaitapur (24 species belonging to 11 families). Habitat wise analysis indicated, maximum number of species from rocky shores mixed with coral patches (33) followed by sandy-muddy (15), weedy and silty-mud (13), sandy (9) and muddy (6). Based on their abundance, the total number of individual of species present in given area were categorised as Abundant, Common, Frequent, Occasional and Rare (Table 1). Common species recorded in all seasons throughout the study area were *Charybdis lucifera, C. annulata, Thalamita crenata, Portunus pelagicus, Leptodius exaratus, Menippe rumphii, Grapsus albolineatus, Metopograpsus messor* and *Ocypode ceratophthalmus*.

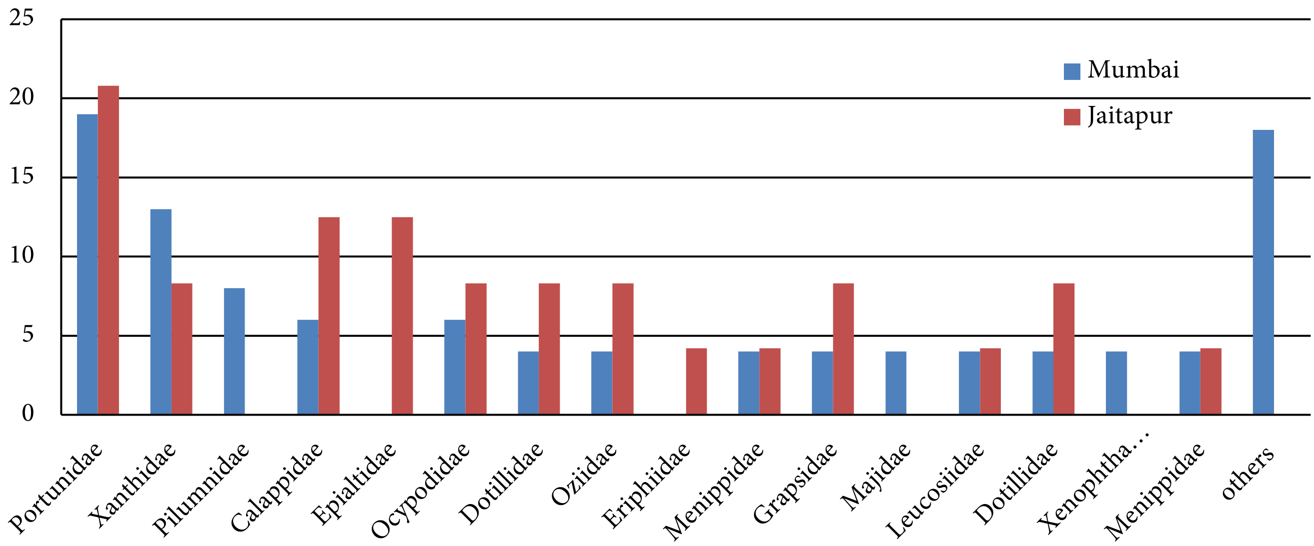

Figure 2. Family wise percentage of species around Mumbai and Jaitapur

Table 1. Abundance and checklist of brachyurans around coastal areas of Mumbai and Jaitapur, Maharashtra

Sr. no.	Species checklist	MD	GR	BA	UT	DV	GI	AM	GG
	Family: Portunidae Rafinesque,1815								
1.	*Scylla serrata* (Forskål, 1775)	-	-	C	F	-	-	-	-
2.	*S. tranquebarica* (Fabricius, 1798)	-	C	-	-	-	-	-	-
3.	*S. olivacea* (Herbst, 1796)*	-	-	-	O	-	-	-	-
4.	*Portunus segnis* (Forskål, 1775)	-	F	F	F	F	F	-	F
5.	*P. sanguinolentus* (Herbst, 1783)	C	-	C	C	C	-	-	C
6.	*Charybdis annulata* (Fabricius, 1798)	F	-	A	O	F	F	F	A
7.	*C. lucifera* (Fabricius, 1798)	A	-	F	F	F	F	F	F
8.	*Charybdis feriatus* (Linnaeus, 1758)	O	-	O	O	-	-	-	-
9.	*Thalamita crenata* Ruppell, 1830	-	-	A	F	-	F	F	F
	Family: Leucosiidae Samouelle, 1819								
10.	*Philyra globus* (Fabricius, 1775)	-	R	-	-	-	-	-	-
11.	*Ryphila cancellus* (Herbst, 1783)	-	-	-	-	C	C	C	-
12.	*Seulocia pubescens* (Miers, 1877)	-	O	-	-	-	-	-	-
	Family: Calappidae De Haan, 1833								
13.	*Ashtoret lunaris*(Forskål, 1775)	-	O	-	-	C	C	C	C
14.	*Matuta planipes* Fabricius, 1798	-	O	-	-	-	-	-	O
15.	*Calappa lophos* (Herbst, 1782)	-	O	-	-	O	-	-	-
	Family: Euryplacidae Stimpson, 1871								
16.	*Trissoplax dentata* (Stimpson, 1858)	-	F	-	-	-	-	-	-
	Family: Oziidae Dana, 1851								
17.	*Ozius rugulosus* Stimpson, 1858**	-	-	C	-	-	-	-	-
18.	*O. tuberculosus* H. Milne Edwards, 1834*	-	-	-	-	-	-	F	-
19.	*Epixanthus frontalis* (Milne Edwards, 1834)	-	C	-	C	C	-	-	C
	Family: Menippidae Ortmann, 1893								
20.	*Myomenniepe hardwickki* (Gray, 1831)	O	-	C	-	-	-	-	-
21.	*Menippe rumphii* (Fabricius, 1798)	A	-	F	-	-	A	C	C
	Family: Eriphiidae MacLeay, 1838								
22.	*Eriphia smithii* MacLeay, 1838	-	-	-	-	-	O	-	-
	Family: Dotillidae Stimpson, 1858								
23.	*Dotilla myctiroides* (H. Milne Edwards, 1852)	-	C	-	C	-	-	A	-
24.	*D. blanfordi* Alcock, 1900	-	C	-	A	-	-	A	-
	Family: Majidae Samouelle, 1819								
25.	*Schizophrys aspera* (H. Milne Edwards, 1834)	F	-	-	-	-	-	-	-
26.	*Prismatopus aculeatus* (H. Milne Edwards, 1834)	-	-	-	-	-	-	-	-
	Family: Inachidae MacLeay, 1838								
27.	*Achaeus cf spinosus***	O	-	-	-	-	-	-	-

Table 1. (continued)

Sr. no.	Species checklist	MD	GR	BA	UT	DV	GI	AM	GG
	Family: Parthenopidae MacLeay, 1838								
28.	*Enoplolambrus pransor* (Herbst, 1796)	-	**R**	-	-	-	-	-	-
	Family: Ocypodidae Rafinesque, 1815								
29.	*Ocypode ceratophthalmus* (Pallas, 1772)	-	**C**	-	**C**	**C**	**F**	**C**	**A**
30.	*O. brevicornis* H. Milne Edwards, 1837*	-	-	-	-	**R**	-	-	-
31.	*Austruca annulipes* (H.Milne Edwards, 1837)	-	**C**	-	-	-	-	-	-
32.	*Gelasimus vocans* (Linnaeus, 1758)	-	**C**	-	-	-	-	-	-
	Family: Grapsidae MacLeay, 1838								
33.	*Metopograpsus messor* (Forskål, 1775)	-	-	**F**	**C**	**F**	**F**	**F**	**F**
34.	*Grapsus albolineatus* Latreille in Milbert, 1812	**A**	-	-	**F**	**F**	**C**	**F**	**F**
	Family: Macrophthalmidae Dana, 1851								
35.	*Macrophthalmus sulcatus* (H.Milne Edwards, 1852)	-	**C**	-	**C**	-	-	-	-
	Family: Plagusiidae Dana, 1851								
36.	*Plagusia squamosa* (Herbst, 1790)	**O**	-	-	-	-	-	-	-
	Family: Varunidae H. Milne Edwards, 1853								
37.	*Varuna litterata* (Fabricius, 1798)	-	**O**	-	-	-	-	-	-
	Family: Xanthidae MacLeay, 1838								
38.	*Leptodius exaratus* (H. Milne Edwards, 1834)	**C**	-	**A**	**C**	**C**	**C**	**C**	**C**
39.	*L. cf sanguineus* (H. Milne Edwards, 1834)**	**R**	-	-	-	-	-	-	-
40.	*Macromedaeus crassimanus* (Milne Edwards, 1867)	-	-	-	-	**R**	-	-	-
41.	*Atergatis laevigatus**	**R**	-	-	-	-	-	-	-
42.	*A. integerrimus* (Lamarck, 1818)	**O**	-	-	-	-	-	-	-
43.	*Atergatopsis amoyensis*	**R**	-	-	-	-	-	-	-
44.	*Demania baccalipes* (Alcock, 1898)	**R**	-	-	-	-	-	-	-
	Family: Epialtidae MacLeay, 1838								
45.	*Menaethius monoceros* (Latreille, 1825)	-	-	-	-	**O**	**O**	-	-
46.	*Doclea rissoni* Leach, 1815	-	-	-	-	-	-	**R**	-
47.	*Hyastenus planasius* (Adams & White, 1848)	**O**	-	-	-	**O**	-	-	-
	Family: Dorippidae MacLeay, 1838								
48.	*Dorippoides facchino* (Herbst, 1785)	-	**R**	-	-	-	-	-	-
	Family: Pilumnidae Samouelle, 1819								
49.	*Pilumnus longicornis* Hilgendorf, 1878	**O**	-	-	-	-	-	-	-
50.	*Heteropilumnus angustifrons* (Alcock, 1900)	**C**	-	**C**	**C**	-	-	-	-

Table 1. (continued)

Sr. no.	Species checklist	MD	GR	BA	UT	DV	GI	AM	GG
51.	*Pilumnopeus convexus* (Maccagno, 1936)*	**O**	-	-	-	-	-	-	-
52.	*Glabropilumnus laevis* (Dana, 1852)	**O**	-	-	-	-	-	-	-
	Family: Hymenosomatidae MacLeay, 1838								
53.	*Elamena cristatipes* Gravely, 1927	**R**	-	-	-	-	-	-	-
	Family: Xenophthalmidae Stimpson, 1858								
54.	*Anomalifrons garthii* (Sankarankutty, 1969)***	**R**	-	-	-	-	-	-	-
55.	*Xenophthalmus wolfii* Takeda & Miyake, 1970**	**O**	**A**	-	-	-	-	-	-

Note: A: Abundant; C: Common; F: Frequent; O: Occasional; R: Rare. *New record from Maharashtra. **New record from west coast of India. ***First record of genus from Indian Ocean.

Table 2. Spearman rank order correlations

Relations	Valid	Spearman	t(N-2)	p-level
pH & Density	24	0.369104	1.862789	0.075899
pH & Biomass	24	0.339889	1.695142	0.104158
Temp & Density	24	0.195686	0.935944	0.359463
Temp & Biomass	24	0.347183	1.736444	0.096470
Salinity & Density	**24**	**0.473565**	**2.521937**	**0.019413**
Salinity & Biomass	24	0.097317	0.458633	0.650996

Note: Spearman Rank Order Correlations MD pairwise deleted. Marked correlations are significant at $p < .05000$.

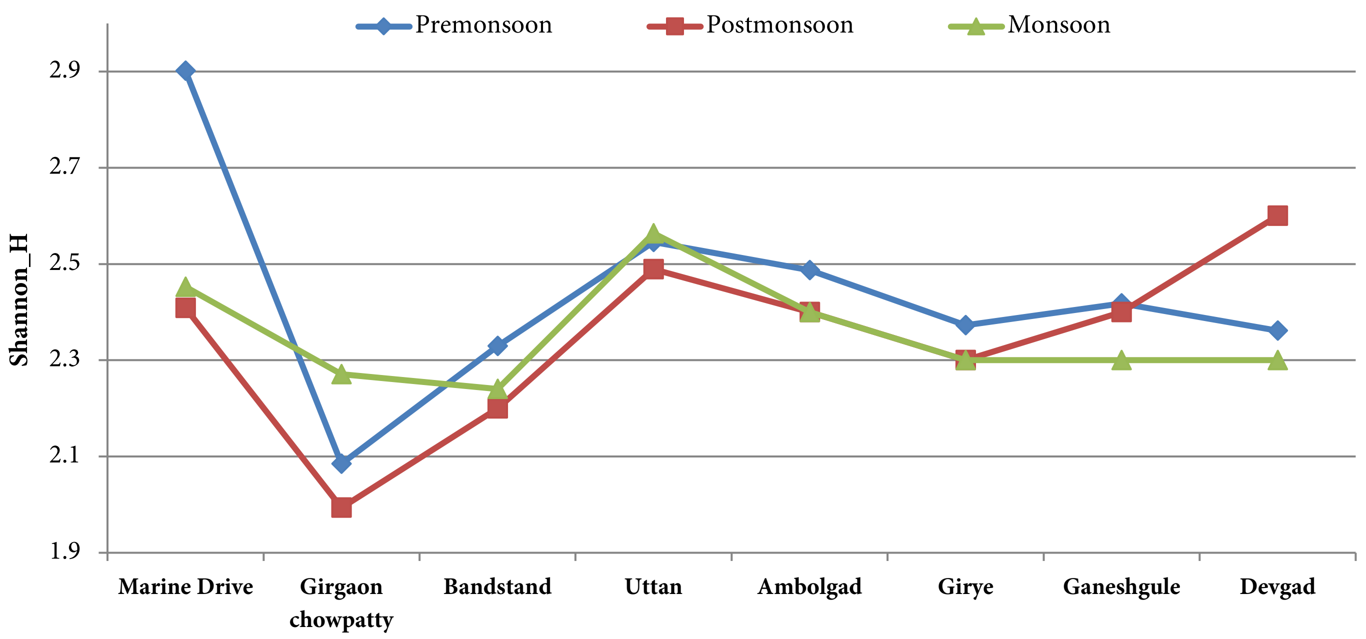

Figure 3. Seasonal and spatial variations in diversity index H' at different sites

Table 3. Diversity indices at different sites at Mumbai and Jaitapur locations

Diversity indices	Total species (S)	Total individuals (N)	Species richness (d)	Pielou's evennes s (J')	Shannon diversity [H'(loge)]	Taxonomic diversity (Delta)	Taxonomic distinctness (Delta*)	Average Taxonomic distinctness (Delta+)	Variation in Taxonomic distinctness (Lambda+)	Average Phylogenetic diversity (Phi+)	Total Phylogenetic diversity (sPhi+)
Marine Drive	25	58	5.911	0.955	3.073	55.753	57.853	57.933	42.396	48.800	1220
Girgaon Chowpatty	18	41	4.578	0.869	2.511	53.951	59.542	59.216	15.071	56.667	1020
Bandstand	13	36	3.349	0.921	2.361	51.492	56.125	53.846	105.720	49.231	640
Uttan	16	40	4.066	0.942	2.611	53.564	57.077	54.667	98.222	48.750	780
Ambolgad	13	41	3.231	0.976	2.505	55.488	59.168	58.974	19.461	58.462	760
Girye	13	37	3.323	0.956	2.452	54.745	58.712	58.205	32.676	56.923	740
Ganeshgule	14	49	3.340	0.935	2.466	53.554	58.153	57.143	57.771	52.857	740
Devgad	15	40	3.795	0.957	2.591	55.051	58.422	58.095	42.086	53.333	800

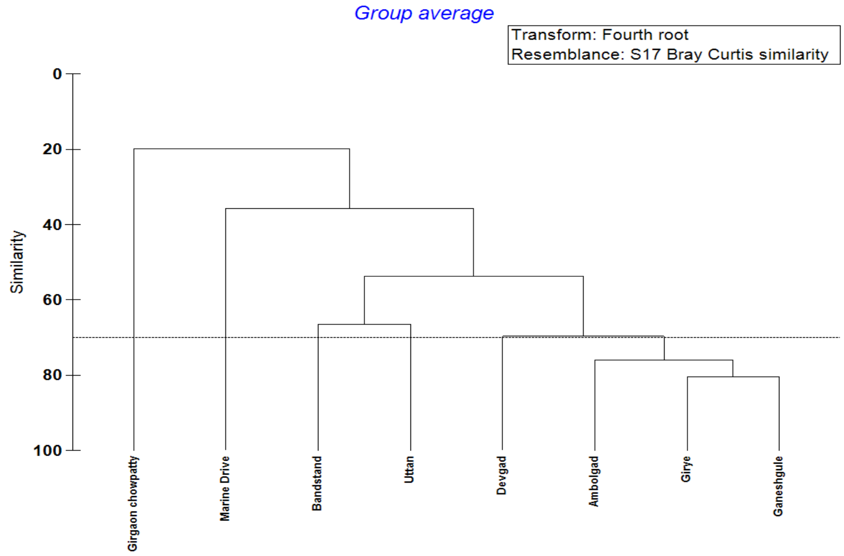

Figure 4. Cluster analysis among all locations of Mumbai and Jaitapur shows 80% of similarity among Jaitapur locations

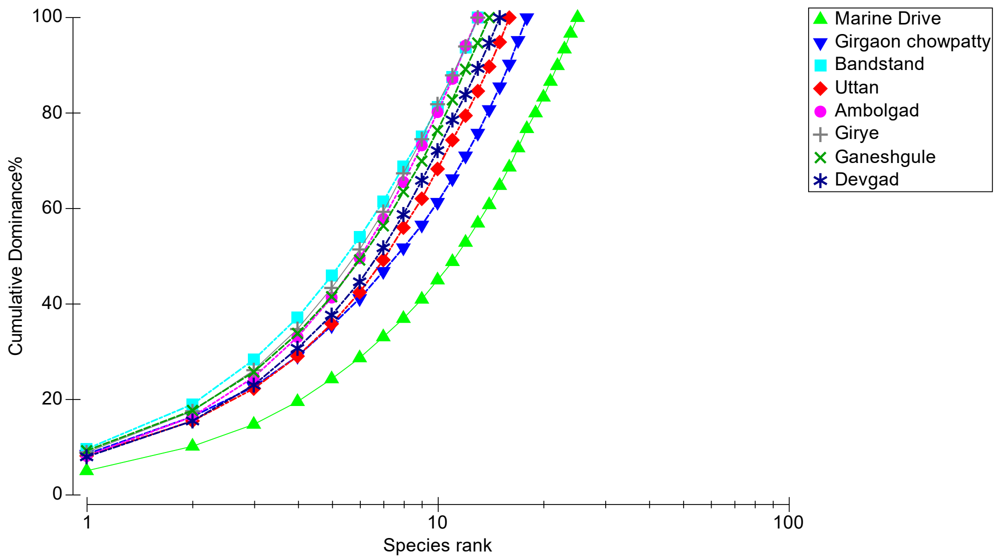

Figure 5. K- dominance plot for all sites (Mumbai locations-Marine Drive, Girgaon Chowpatty, Bandstand, Uttan; Jaitapur locations-Ambolgad, Girye,Ganeshgule, Devgad)

Diversity Indices Estimated for Location Around Mumbai and Jaitapur

The diversity indices are presented in Table 3. The Shannon-Weiner index (H') values varied between 2.3 and 3.0 for Mumbai as well as Jaitapur. Maximum value (3.0) was recorded at Marine Drive site. Season wise analysis revealed maximum diversity in pre monsoon and post monsoon (Figure 3). The evenness varied between 0.86 and 0.97, whereas the richness fluctuated between 3.2 and 5.9. Maximum richness was recorded at Marine Drive as the species were evenly distributed while maximum evenness was recorded at Ambolgad. The minimum (51.49) and maximum (55.75) taxonomic diversity was recorded at Bandstand and Marine Drive, respectively. The taxonomic distinctness was more in Bandstand (59.54) and Ambolgad (59.16). The average taxonomic distinctness was high in Girgaon Chowpatty (59.21) and Ambolgad (58.97) than Bandstand (53.84). The variation in taxonomic distinctness was maximum at Bandstand (105.72) and Uttan (98.2). The average phylogenetic diversity was maximum at Ambolgad (58.46) and minimum at Uttan and Marine Drive (48.8). Total phylogenetic diversity was maximum at Marine Drive (1220) and minimum at Bandstand (640).

The dendrogram revealed four separate clusters for all seven locations (Figure 4). Maximum similarity was recorded between stations Girye and Ganeshgule (80.41%) at Jaitapur, and between Bandstand and Uttan (66.5%) in Mumbai region. Girgaon Chowpatty is totally different from other locations in terms of substratum (sandy, muddy and silty) and hence species variation was also observed. The average dissimilarity in species composition of crabs from Marine Drive and Girgaon Chowpatty was 97.9%, where *Dotilla* spp was responsible for 10.3% of dissimilarity between two stations. The maximum species dominance was recorded at Girgaon Chowpatty and Bandstand (Figure 5) on account of dominance of *Dotilla* spp and *Xenophthalmus wolffi*. According to W statistics, the ABC curve seems quite healthy, indicating undisturbed community at all locations except at Bandstand and Ganeshgule where moderate disturbance is seen (Figure 6 a-h). Funnel plot and ellipse plot revealed clear separation of Bandstand and Uttan, as these are more diverse from other locations (Figures 7-9). The species (*Ozius rugulosus, S. serrata* and *S. olivacea*) were recorded only once from Bandstand and Uttan, unlike other locations. Overall results indicate Jaitapur locations as more diverse than Mumbai, with respect to average taxonomic distinctness.

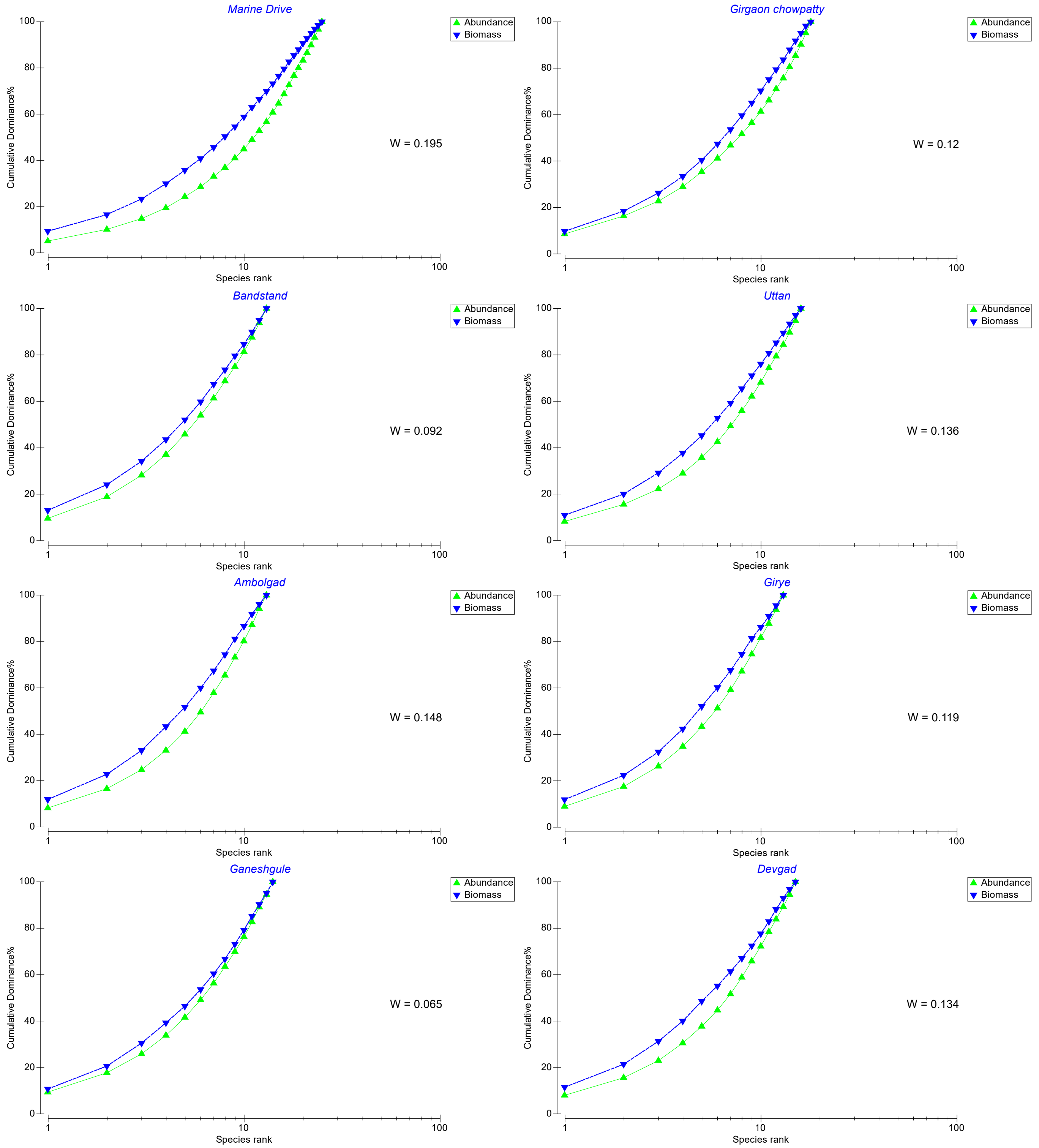

Figure 6. ABC curve for all locations (a-Marine Drive, b-Girgaon Chowpatty, c-Bandstand, d-Uttan, e-Ambolgad, f-Girye, g-Ganeshgule, h-Devgad)

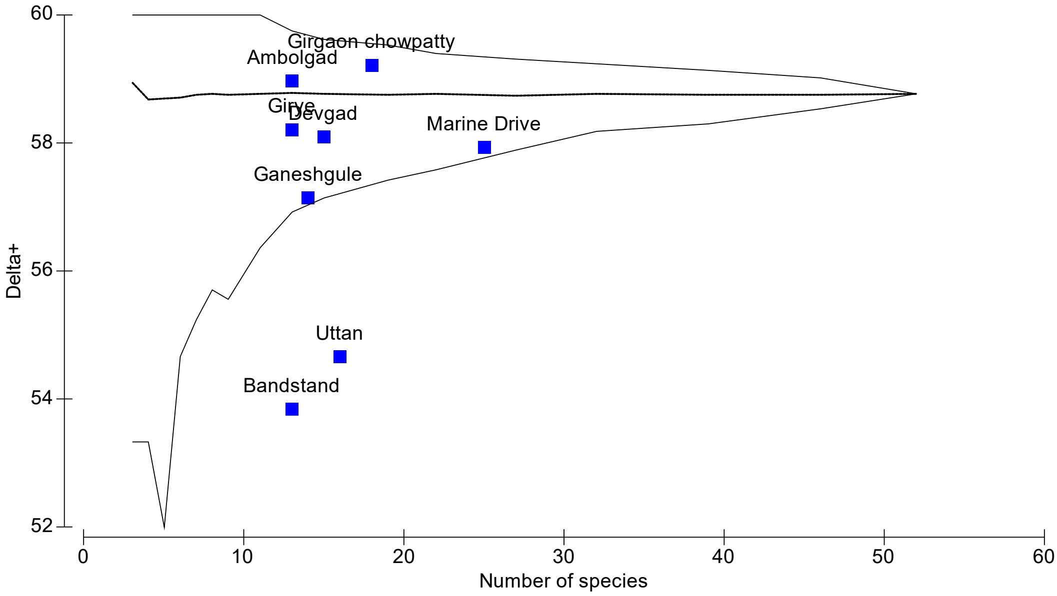

Figure 7. Funnel plot of average taxonomic distinctness for all locations

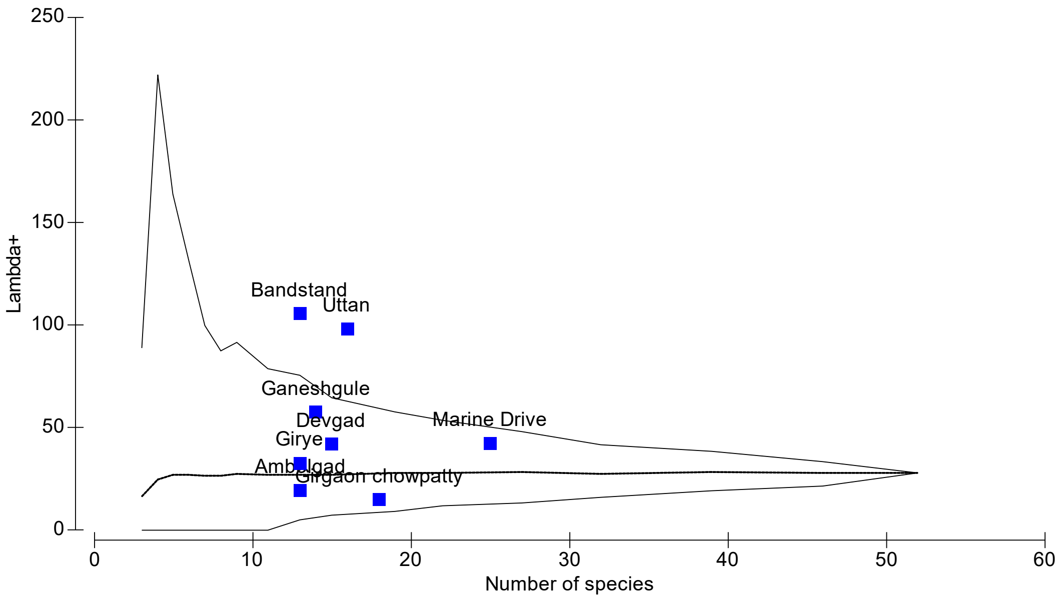

Figure 8. Funnel plot of variation in taxonomic distinctness for all locations

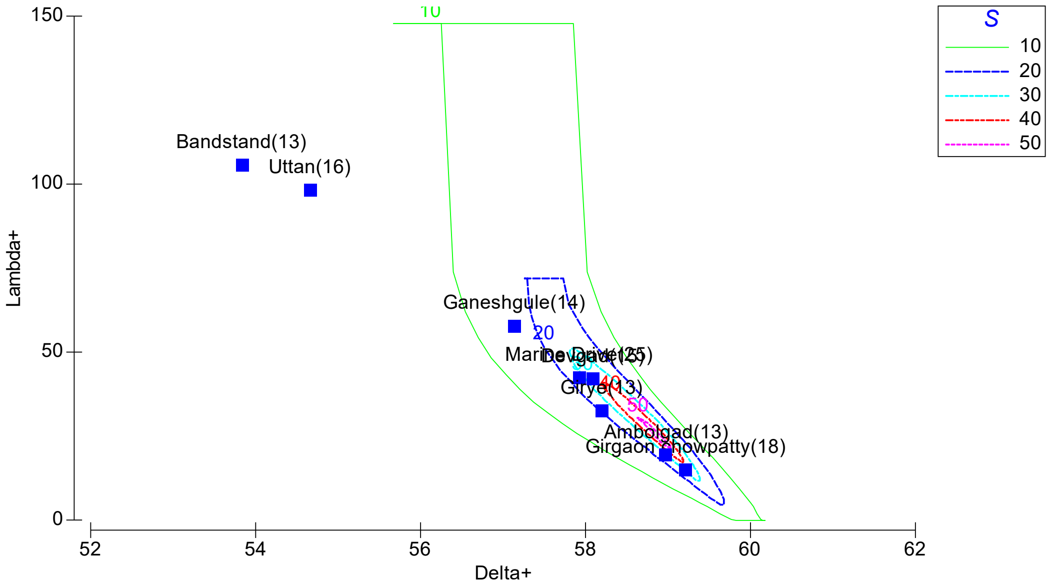

Figure 9. Ellipse plot of average taxonomic distinctness (delta+) and variation in taxonomic distinctness (lambda+) at all locations

The present study also reports total 10 species with 4 new records from intertidal regions of west coast of India (*Xenophthalmus wolfii, Ozius rugulosus, Achaeus cf spinosus, Leptodius cf sanguines*); 5 new distributional records for Maharashtra state (*Ozius tuberculosus, Ocypode brevicornis, Atergatis laevigatus, Pilumnopeus convexsus, Scylla olivacea*); and 1 first record of genus from Indian Ocean (*Anomalifrons garthii*) (Figures 10-18).

Figure 11. *Pilumnopeus convexsus*

Figure 10. *Atergatis laevigatus*

Figure 12. *Ocypode brevicornis*

Figure 13. *Achaeus cf spinosus*

Figure 14. *Leptodius cf sanguineus*

Figure 15. *Ozius rugulosus*

Figure 16. *Ozius tuberculosus*

Figure 17. *Anomalifrons garthi*

Figure 18. *Xenophthalmus wolfii*

Discussion

The data gathered during the present study suggests that the diversity of crabs is profoundly influenced by the nature of the habitat. As Jaitapur is approximately 300km away from Mumbai, differences were observed in climate; habitat and nature of soil that could be responsible for species variation in Mumbai and Jaitapur locations. Observations recorded around Mumbai locations indicated Girgaon and Uttan areas to be more polluted as compared to Marine Drive and Bandstand. Uttan beach is polluted by oil spills, chemical, plastics and domestic sewage brought by Manori and Vasai creeks. Girgaon

Chowpatty and Bandstand are famous recreational spots, hence maximum quantity of waste (plastic & litter) was observed here, whereas Bandstand is polluted mostly due to domestic sewage. Marine Drive shore is covered by cement tripods, restricting anthropogenic activity but two outlets of effluent discharges from townships are responsible for degradation of this area. Around Jaitapur, Girye area is less polluted; Ambolgad is slightly affected by domestic sewage, whereas Ganeshgule and Devgad is moderately affected by tourist activity.

The variations in the density, biomass and dominance of species in different ecological zones like reef lagoon, reef flat, reef flat with crest was reported by Iglesias & Raso (1999). Al-Wazzan et al. (2020) reported that gleaning activity removes the crab and damages the physical structure by breaking and turning upside down the rocks. Khot et al. (2019a) also supported this view and reported the effect of gleaning on the density and biomass of crabs from coastal areas of Mumbai. In the present study, variation in species as per habitat and zonation was recorded similar to reports from different geographical areas.

The present study reports 33 species from rocky coral reef mixed habitat alone. De Szechy et al. (2001) recorded 12 species of brachyuran crabs from the rocky shores of Rio de Janeiro and Sao Paulo of Brazil; whereas, Flores & Paula (2001) recorded 7 species from rocky shore of central Portugal. Trivedi et al. (2012) reported 19 species of brachyuran crabs from different habitats of Gulf of Kutch, India, while Dev Roy (2013) reported 49 species of brachyuran crabs from coral reef habitat from west coast of India.

Family wise dominance was reported from Kanyakumari area (Sruthi et al., 2014), mangrove ecosystem of Uran, Maharashtra (Pawar, 2017), Gujarat (Beleem, 2018). They also reported maximum number of species in Portunidae followed by Xanthidae, Pilumnidae, Calappidae and Epialtidae, similar to the findings of the present study. Based on abundance and spatiotemporal collection, Vignoli et al. (2004) separated decapod crustaceans into Common, Rare, Abundant categories. Kumar et al. (2007) classified *Portunus* spp, *Charybdis* spp, *Matuta* spp, *Scylla* spp, as abundant species. Pawar (2012) categorized species distribution as common (*Scylla serrata* and *Leptodius exaratus*) and occasional (*Portunus pelagicus, P. sanguinolentus* and *Charybdis cruciata*), which is in agreement with the findings of present study.

With respect to species and location, species reported by Bi-Shaikh (2002) and Lokhande et al. (2015) from oyster zone at Colaba (*Uca annulipes, U. vocans, Menippe rumphi, Leptodius crassimanus, Heteropilumnus angustifrons*) and Mirya Bay, Ratnagiri district (*Ocypode ceratophthalmus, Ashtoret lunaris* and *Philrya corallicola*), respectively, are similar to the findings of the present study. The present study reports 3 new records from Maharashtra state (Khot et al., 2021), 1 new record from west coast of Maharashtra and 1 new record of genus from Indian Ocean (Khot et al., 2019b).

Rocky shores are the most dynamic habitats subjected to varying degrees of environmental factors such as winds, tidal waves, salinity, slope, temperature, desiccation etc. which may have direct impact on diversity and distribution of flora and fauna inhabiting the rocky shore. The salinity and substratum characteristics are the most important key factors that can influence the spatial distribution of brachyuran crabs (Macintosh, 1988; Balasubramanian & Kannan 2005; Sridhar et al., 2006). It also plays vital role in regulating physiology of marine organisms (Lesser, 2006). Thus, it is also responsible for the reduction in number of species from particular areas (Varadharajan et al., 2009, 2013; Pandya, 2011; Pandya & Vachhrajani, 2011). During the present study, a significant correlation (R=0.47, P=0.01) was found between salinity and density of crabs. This could be related to temperature which is responsible for rates evaporation. However, lower salinity recorded during was the result of influx of rain water into the sea.

Temperature is the most important factor of all the physical environmental factors, which controls the life history of marine organisms. Water temperature is relatively less (24-26° C) in the Arabian Sea and Bay of Bengal during the time of the northeast monsoon than other seasons. During the summer months, the temperature gradient runs approximately north-south on both the sides of the Indian coasts, with highest values of 32°C (Venkatraman, 2007). The results of present study are in agreement with many other workers (Subrahmanyan, 1959; Nair et al., 1980; Achuthankutty et al., 1981; Joydos, 2002; Bindhu, 2006; Sawant et al., 2007; Kadam & Tiwari, 2011; Paralkar, 2012; Gadhavi, 2015; Lokhande et al., 2015). The non-significant relation between temperature and abundance of crab indicates that these organisms are adapted to take shelter under rocks, crevices or other hideouts in extreme temperatures. Paralkar (2012) opined that the influx of fresh water during monsoon largely affects the buffering in nearshore and estuarine systems and bringing pH below 8.0. However, a non-significant relationship was seen with pH and density.

Species diversity is a measure of community structure and most important parameter to understand the health status and productivity of an ecosystem. In present study, Shannon-Weiner index ranged from 2.3 to 3.0, indicating very moderate pollution and Margalef's richness ranged of 3.2 to 5.9, indicating rich diversity. Thus, evaluation of the species diversity, richness, evenness and dominance based on the biological components of the ecosystems are essential to know detrimental changes in the environment. The Shannon-Weiner diversity index (*H'*) is widely used for comparison of diversity between different habitats (Clark & Warwick, 2001). In healthy environment, Shannon-Weiner index range between 2.5 and 3.5 (Ajmal Khan et al., 2005; Magurran, 1988). Wilhm & Dorris (1996) stated diversity values <1.0, in estuarine waters with heavy pollution. Values between 1.0 and 3.0 indicated moderate pollution where values exceeding 3.0 characterised unpolluted waters.

Maximum diversity and richness was recorded from Marine Drive, as it favoured ecological microhabitat for crabs, comprising of coral reefs, seaweed cover, silty-muddy bottom, coral boulders with sponges, rocky crevices, rocks covered with zoanthids and gorgoniids. Different authors have reported similar results from different areas and habitats. Beleem et al. (2014) reported values of *H'*, *J'* and *d* as 0.84 to 2.4, 0.76 to 0.91 and 3.33 to 0.65, respectively, from Diu coast of Gujarat. Hebling et al. (1994) reported range of *H′* (0 to 1.99) and *J′* values (0 to 0.71) based on the majoid crab of Ubatuba. Similar results were obtained on the brachyuran communities from the same Ubatuba area by Fransozo et al. (1993) and Carmona-Suarez (2000). In present study, maximum evenness was recorded from Devgad and Uttan locations, while lower value of evenness was recorded from Girgaon Chowpatty (0.86). The reason for lower evenness is dominance of two species *Dotilla* spp and *Xenophthalmus* sp. Both species were dominant as the habitat is comprised of sand-silt and muddy bottom, with food availability from surrounding areas and tidal flow favoured them to reproduce and grow both species. They contributed 16.5% of the total fauna, resulting in lower *H'* values (Kumar & Wesley, 2010). Richardson (2004) noted that the dominance of single foraminifera community in Twin Cays, Belize resulted in reduction of evenness. In the present study, Mumbai and Jaitapur locations showed high similarity. On the other hand, the contribution to dissimilarity, between the two locations, was attributed to conditions at Marine Drive and Girgaon Chowpatty of Mumbai. Kumar & Wesley (2010) reported dissimilarity between sites from Maldives. Jitpukdee et al. (2015) showed clear separation of benthic macrofauna at different stations based on cluster analysis. In the present study, the MDS plot displayed clear separation of Girgaon Chowpatty from other locations due to difference in habitats. Clarke & Warwick (2001) stated a stress value of < 0.10 - 0.20 to provide a good representation. In the present study, the 2D stress value was found to be 0.01, displaying significant separation between sampling locations. In present study, dominance of Dotillids and Xenophthalmids was recorded from Girgaon Chowpatty. According to W statistics, in the present study, the ABC curve seems quite healthy, except at Bandstand and Ganeshgule which indicated moderate disturbance. The findings are in agreement with report of Jaiswar et al. (2007a, 2007b). However, the moderate disturbance could be attributed to the inclusion of small non-commercial species in analysis whose weight was almost negligible and effect of tourism at both sites. Ajmal Khan et al. (2005) used the conventional and the new indices to compare the diversity of brachyuran crabs in two mangrove areas (natural and artificial). Shan et al. (2010) showed positive correlation with species richness and Shannon diversity with average taxonomic distinctness (AvTD) and negative correlation with variation in taxonomic distinctness (varTD). Ellingsen et al. (2005) applied taxonomic distinctness as a diversity measure on benthos of Norwegian continental shelf and found that annelids and crustaceans were positively correlated to latitude and depth whereas mollusc were not related to latitude and depth. In present study, no relationship was seen between new diversity indices and traditional diversity indices as well as with other diverse groups, though found by others (macrobenthos: Warwick & Clarke, 1995; Clarke & Warwick, 1998; asteroids: Price et al., 1999; copepods: Woodd-Walker et al., 2002; fish: Hall & Greenstreet, 1998; Rogers et al., 1999; corals: Brown et al., 2002). Species diversity index was reported to be maximum (2.98) in monsoon in Kerala coast (Kumar et al., 2007), maximum diversity (0.492) at Wilson Island (Kumaralingam et al., 2012), from Pondicherry and Pichavaram mangrove ecosystem east coast of India (Ravichandran et al., 2001, 2007; Ajmal Khan et al., 2005; Soundarapandian et al., 2008; Satheeshkumar, 2012; Kamalakkannan, 2015; Prasanna et al., 2017). In India, very limited investigators have reported brachyurans from mangroves of west coast (Haragi et al., 2010; Bandekar & Kakati, 2011; Shukla et al., 2013; Pawar, 2012, 2015, 2017). The present study reports significant spatial variation between sites ($p=0.0001$, $P<0.05$) and non-significant temporal variation between seasons ($p=0.55$, $P>0.05$) with Shannon diversity and evenness values which supported with the findings of Kumar & Wesley (2010); Jeyabaskaran (1997) and Flores & Paula (2001). The values of richness index showed both non-significant temporal and spatial variation between seasons and sites.

Conclusion

In the present study, a checklist and diversity of brachyuran crabs inhabiting along intertidal and shallow subtidal regions of Mumbai and Jaitapur coasts of Maharashtra were surveyed with findings of total 55 species of brachyuran crabs. The study showed rich diversity among both the coasts with different types of habitats where rocky habitat mixed with coral patches showed maximum diversity. Furthermore, new records were also reported from west coast of India and genera from Indian Ocean. The data obtained from present study can be used as baseline data and reference datasets for identification of brachyuran crabs for research studies on marine crab's taxonomy along Maharashtra coast in future. In order to conserve and sustainability use the biodiversity, continuous monitoring and surveys are required for future research.

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Compliance With Ethical Standards

Authors' Contributions

MK: Conceptualization, Formal analysis, Data curation, Visualization, Writing – original draft, Writing – review & editing

AKJ: Conceptualization, Formal analysis, Writing – review & editing

AKP: Writing – review & editing

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

All data generated or analysed during this study are included in this published article.

AI Disclosure

The authors confirm that no generative AI was used in writing this manuscript or creating images, tables, or graphics.

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