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Species assemblages and community structure of deep-sea demersal ichthyofauna of the South-eastern Arabian Sea (SEAS)

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Studies of species assemblages and community structure are of vital importance in the deep-sea realm. Data for the present study were collected during the research expedition of FORV 'Sagar Sampada' in the latitude 8.02°N and 11.58°N, longitude 74.16°E and 78.35°E. High Speed Demersal Trawl – Crustacean Version (HSDT-CV) was used for the operations at a depth of 200 and 1000 m. The total catch came to 2148.35 kg from 10 stations. An analysis of the catch composition was made. Total catch was dominated by Priacanthus hamrur *(27.66%) followed by* Neoepinnula orientalis *(15.57%),* Psenopsis cyanea *(10.05%),* Glyptophidium oceanium *(3.55%),* Lamprogrammus niger *(3.17%),* Narcine timlei *(3.08%),* Lamprogrammus *sp. (2.6%),* Pterigotrygla hemisticta *(2.17%). About 76 species recorded from 22 orders were identified. The diversity indices, Cluster analysis, k-dominance plot were analysed using PRIMER v6 software. The diversity indices including Margalef richness index (d), Shanon index (log e^2), Pielou's evenness index (J′) and Simpson diversity index (1 − λ) were calculated. Diversity indices were compared with the previous studies in the same area, and this can be a reference point for future studies.*

Keywords: Deep-sea, demersal ichthyofauna, community structure, diversity indices

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INTRODUCTION

The fisheries sector plays a vital role in Indian economic development, provides nutritional security and creates many employment opportunities. Indian marine fish production depend on coastal waters and about 90% of the catch comes from depths starting at 50 m (Balachandran *et al.*, 1996). Poor technology and economic viability are the important constraints in the exploration of deep-sea resources. Unfortunately, only a few of the maritime states in India are exploring deep-sea fishery (Mathew, 2003). Therefore, the exploration of deep-sea resources is important for increased fish production in the country.

In the global aspects of biodiversity, deep-slopes and deep-reefs are the two habitats where most new marine taxa are likely to be found (Eschmeyer *et al.*, 2010). The general characters of deep-sea fishes are high longevity, slow growth, late maturity and low fecundity, which means the deep sea is the most vulnerable ecosystem and its recovery will be slow (Moratto *et al.*, 2006). Studies about the deep-water community structure from the South-eastern Arabian Sea are limited; there have not been many attempts to investigate the species assemblage and community structure. Hitherto, surveys of Fisheries Oceanographic Research Vessel (FORV) 'Sagar Sampada' have contributed significant information on deep-sea fishery resources of India (Nair & Joseph, 1984; Sivakami, 1989; James & Pillai, 1990; Panicker *et al.*, 1993; Khan *et al.*, 1996; Venu & Kurup, 2002; Jayaprakash *et al.*, 2006).

Studies on species abundance distribution and community structure of the area are scarce, while some limited studies are available (Hashim, 2012; Sudhakar *et al.*, 2013). This study focuses on the community structure of the demersal ichthyofauna of the South-eastern Arabian Sea. However, continuous study and monitoring of the diversity plays a vital role in the conservation of the deep-sea ichthyofauna. With this study, we aimed to explore the species assemblages and community structure of the deep-sea habitat of the South-eastern Arabian Sea. This study also investigated the changes in the community structure of two extremes of the mesopelagic zone (200 and 1000 m depth).

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MATERIALS AND METHODS

The study area lies between 8.02–11.58°N 74.16–78.35°E (Figure 1) off the South-east Arabian Sea. Samples for this study have been collected during the FORV 'Sagar Sampada' Cruise No: 322-research expedition, in the depth zone of ~200 and ~1000 m, from 6–19 January 2014. Stations with depths ranging from 180 to 220 m were considered ~200 m depth and stations with depths ranging from 970 m to 1110 were considered ~1000 m.

High Speed Demersal Trawl II (HSDT, 38 m) and Expo-model Demersal Trawls (45.6 m) were used for the fishing operations. The ground was scanned using a SIMRAD EK 60 echo-sounder to determine the most suitable sea bottom for trawling. The stations were fixed using a

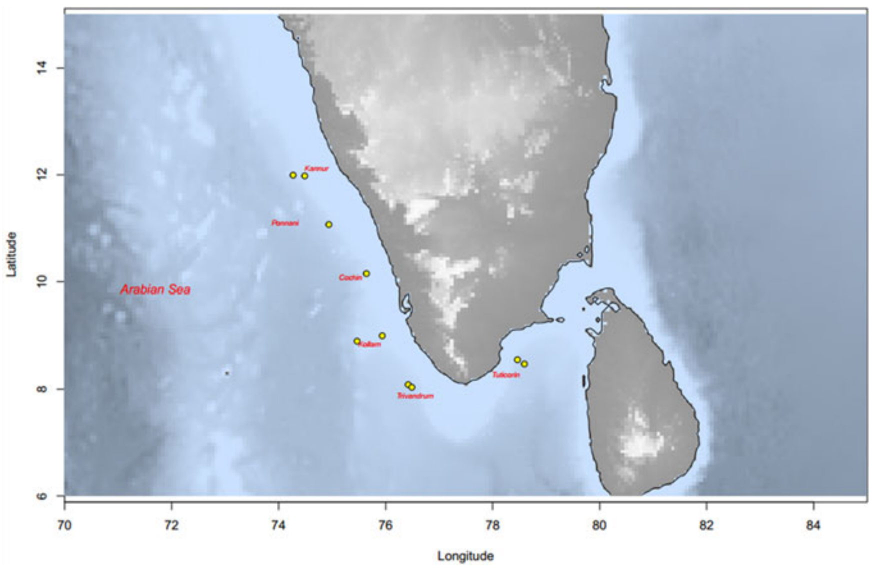

Fig. 1. Map showing the study area and sampling stations.

navigation chart. Speed of the vessel was kept at 3.5–4.5 knots and the duration of the operation was standardized to 1 h. Map of study area and sampling sites are created using R software (R Core Team, 2016) with marmap package (Eric & Benoit, 2013).

The collected samples were identified based on the publications of Alcock (1899), Smith & Heemstra (1986), FishBase (Froese & Pauly, 2016) and classification was made using the Catalog of Fishes online (Eschmeyer *et al.*, 2016). Diversity indices and community structure were calculated using PRIMER Version 6 for windows (Clarke & Warwick, 2001; Clarke & Gorley, 2006). We were used only fishes for analysis because the current study is about the species assemblages and community structure of demersal ichthyofauna.

Based on the individual species data of each transect, diversity indices including Margalef's richness index (d), Shannon diversity index (H′log2), Pielou's evenness index (J') and Simpson diversity index ($1 - \lambda$) were calculated.

Cluster analysis was done to find out the similarities between stations, using the Bray–Curtis coefficient hierarchical agglomeration method and was used to produce the dendrogram from the square root transformed data. The species were ranked in terms of abundance, the ranked abundances were calculated as percentages of the total abundances of all species and were plotted against the relevant species rank. K-dominance curves were constructed to ascertain the dominant species at each site and understand its contribution in the total diversity; it helps in comparing different sites qualitatively.

RESULTS

The total catch (Table 1), catch composition is presented in Figure 2. Perciformes dominated with 42.72%, followed by Ophidiiformes (27.40%), Scorpaeniformes (5.82%), and Aulopiformes (4.08%), Myctophiformes (3.18%), Salmoniformes (2.12%).

Species composition

From the catch composition (Figure 2), we can conclude that our study area is dominated with Perciformes (42.72%) and is also composed with Ophidiiformes (27.40%), Scorpaeniformes (5.82%), Aulopiformes (4.08%), Myctophiformes (3.18%) and Salmoniformes (2.12%).

Table 1. Total catch at different depths from the South-east Arabian Sea.

Station no.	Off the coast of	Latitude (°N)	Longitude (°E)	Average depth (m)	Total catch (kg)
1	Cape Comorin	8.29.994	78.35.583	1000	74.90
2	Cape Comorin	8.28.994	78.35.583	200	169.45
3	Trivandrum	8.05.718	76.25.842	1000	189.70
4	Trivandrum	8.02.175	76.29.800	200	147.95
5	Kollam	8.53.593	75.27.288	1000	452.55
6	Kollam	8.59.618	75.55.468	200	122.40
7	Cochin	10.09.956	75.38.965	200	34.10
8	Ponnani	11.04.195	74.55.430	1000	255.65
9	Kannur	11.58.355	74.16.791	1000	120.10
10	Kannur	11.57.317	74.26.081	200	581.55
Total catch					**2148.35**

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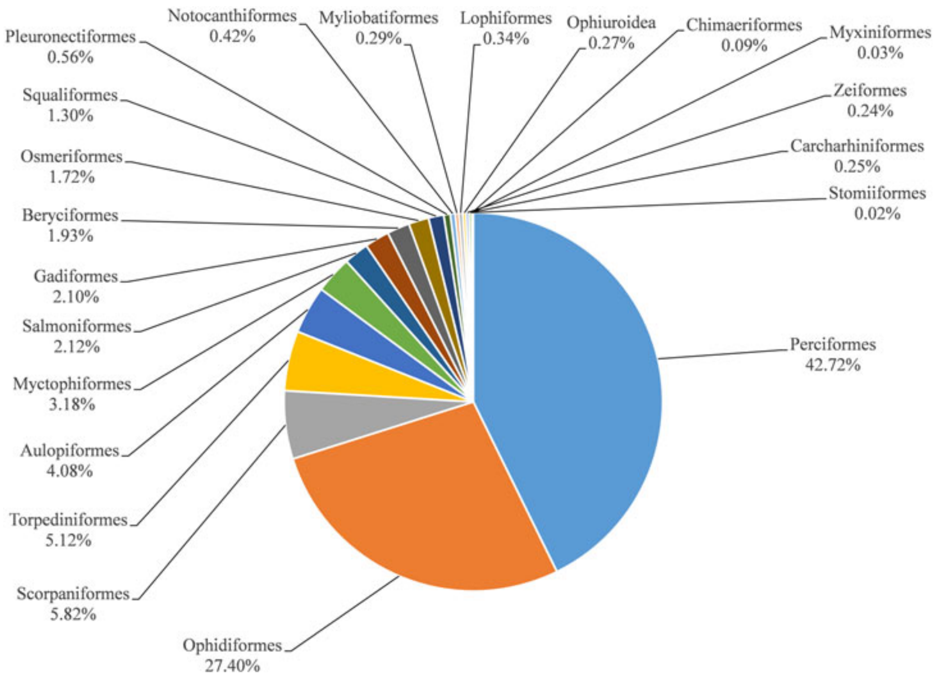

Fig. 2. Composition of demersal fishes of the South-east Arabian Sea.

The total ichthyofaunal biomass is composed of 76 species from 22 orders and the composition of each species is sorted in percentage (Table 2). The catch composition is dominated by *Priacanthus hamrur* (Forsskål, 1775) (27.66%) and composed with other major species: *Neoepinnula orientalis* (15.57%), *Psenopsis cyanea* (10.05%), *Glyptophidium oceanium* (3.55%).

Diversity indices

The cluster analysis and k-dominance plot were constructed using Primer Version v6 (Clarke & Gorley, 2006). The calculated diversity indices are Margalef's richness index (d) (Margalef, 1958), Shannon index ($\log e^2$) (Shannon & Weaver, 1949), Pielou's evenness index (J') (Pielou, 1966) and Simpson diversity index ($1 - \lambda$) (Table 3).

Margalef's richness index (d)

Margalef's richness index (d), weights number of species in the community rather than individuals. It is estimated that the normal value of Margalef's index lies between 2.5–3.5 in a healthy environment (Khan *et al.*, 2004). In this study, Margalef's richness index for 200 m varies between 1.80–3.40 with an average of 2.79 and for 1000 m depth varies between 3.43–4.02, with an average of 3.72. Maximum value observed is 4.02 at 1000 m depth (11.85°N 74.16°E) and minimum value observed is 1.80 at 200 m depth (11.57°N 74.26°E). Margalef's richness is slightly higher at 200 m and 1000 m depth, which is higher than previous studies Sudhakar *et al.*, 2013 (Table 4).

Shannon diversity index ($\log e^2$)

During the present study, Shannon diversity index for 200 m varies between 1.62–3.52 with an average of 2.57 and varies between 3.28–3.86 at 1000 m depth, with an average of 3.57. Maximum value observed is 3.86 at 1000 m depth (8.29°N 78.35°E), minimum value observed is 1.62 (8.02°N 76.29°E). The Shannon diversity index (which takes into account the number of individuals as well as number of taxa) varies between 0.0–5.0 (Turkmen & Kazanci, 2010). More than 4.5 is uncommon (Magurran, 2004). Values of Shannon diversity index are slightly higher than the values of the previous studies of Sudhakar *et al.* (2013) (Table 4).

Pielou's evenness index (J')

Equitability is often expressed as Pielou's evenness index (J'), and the value lies between one and zero. The index refers how close numbers of each species are in an ecosystem. It is a measure of diversity, which refers to the equality of species numbers in a community structure. In this study, Pielou's evenness index for 200 m varies between 0.34–0.81 with an average of 0.57 and for 1000 m depth varies between 0.71–0.78 with an average of 0.74. For 200 m depth, Pielou's evenness is higher than the previous report of Sudhakar *et al.* (2013), while values are lower for the 1000 m study (Table 4).

Simpson diversity index ($1 - \lambda$)

The Simpson index $1 - \lambda$ is an equitability or evenness index and the value of $1 - \lambda$ is always <1. In this study, we observed that the Simpson ($1 - \lambda$) of the South-eastern Arabian Sea varies between 0.49–0.91 with an average of 0.80.

Cluster analysis

Cluster analysis is a technique in which sequences are linked together according to their similarities and produces a two dimensional dendrogram. The vertical axis of the dendrogram

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Table 2. Species composition of demersal ichthyofauna from the South-east Arabian Sea.

Sl no	Species	% of composition
1	*Priacanthus hamrur* (Forsskål, 1775)	27.66
2	*Neoepinnula orientalis* (Gilchrist & von Bonde, 1924)	15.57
3	*Psenopsis cyanea* (Alcock, 1890)	10.05
4	*Glyptophidium oceanium* (Smith & Radcliffe, 1913)	3.55
5	*Lamprogrammus niger* (Alcock, 1891)	3.17
6	*Narcine timlei* (Bloch & Schneider,1801)	3.08
7	*Lamprogrammus* sp. (Brauer, 1906)	2.60
8	*Pterigotrygla hemisticta* (Temminck & Schlegel, 1843)	2.17
9	*Lamprogrammus brunswigi* (Brauer, 1906)	2.12
10	*Diaphus diadematus* (Tåning, 1932)	2.11
11	*Rouleina attrita* (Vaillant, 1888)	1.87
12	*Cubiceps whiteleggii* (Waite, 1894)	1.84
13	*Hoplostethus melanopus* (Weber, 1913)	1.52
14	*Alepocephalus bicolor* (Alcock, 1891)	1.43
15	*Bathyuroconger braueri* (Weber & de Beaufort, 1916)	1.33
16	*Benthobatis moresbyi* (Alcock, 1898)	1.33
17	*Bathyclupea hoskynii* (Alcock, 1891)	1.21
18	*Bathyuroconger vicinus* (Vaillant, 1888)	1.17
19	*Bembrops caudimacula* (Steindachner, 1876)	1.11
20	*Chelidoperca investigatoris* (Alcock, 1890)	1.08
21	*Satyrichthys laticeps* (Schlegel, 1852)	1.08
22	*Platycephalus indicus* (Linnaeus, 1758)	0.87
23	*Myctophum punctatum* (Rafinesque, 1810)	0.76
24	*Dicrolene multifilis* (Alcock, 1889)	0.76
25	*Echinorhinus brucus* (Bonnaterre, 1788)	0.71
26	*Synapobranchus affinis* (Günther, 1877)	0.65
27	*Coryphaenoides armatus* (Hector, 1875)	0.54
28	*Bathynomus giganteus* (Milne-Edwards, 1879)	0.50
29	*Centrophorus squamosus* (Bonnaterre, 1788)	0.49
30	*Chlorophthalmus corniger* (Alcock, 1894)	0.43
31	*Bathygadus favosus* (Goode & Bean, 1886)	0.38
32	*Chascanopsetta lugubris* (Alcock, 1894)	0.37
33	*Plesiobatis daviesi* (Wallace, 1967)	0.37
34	*Luciobrotula bartschi* (Smith & Radcliffe, 1913)	0.36
35	*Gempylus serpens* (Cuvier, 1829)	0.36
36	*Beryx splendens* (Lowe, 1834)	0.35
37	*Zenopsis conchifer* (Lowe, 1852)	0.33
38	*Eridacnis radcliffei* (Smith, 1913)	0.30
39	*Halosauropsis macrochir* (Günther, 1878)	0.29
40	*Physiculus capensis* (Gilchrist, 1922)	0.26
41	*Uranoscopus crassiceps* (Alcock, 1890)	0.25
42	*Cynoglossus* sp.	0.25
43	*Lophiomus setigerus* (Vahl, 1797)	0.24
44	*Nezumia sclerorhynchus* (Valenciennes, 1838)	0.24
45	*Dicrolene nigricaudis* (Alcock, 1891)	0.24
46	*Halimochirurgus alcocki* (Weber, 1913)	0.23
47	*Bassozetus robustus* (Smith & Radcliffe, 1913)	0.20
48	*Lamprogrammus niger* (Alcock, 1891)	0.17
49	*Halosaurus ovenii* (Johnson, 1864)	0.15
50	*Bathypterois dubius* (Vaillant, 1888)	0.14
51	*Halieutaea stellata* (Vahl, 1797)	0.14
52	*Trichiurus lepturus* (Linnaeus, 1758)	0.14
53	*Hydrolagus africanus* (Gilchrist, 1922)	0.13
54	*Glyptophidium oceanium* (Smith & Radcliffe, 1913)	0.13
55	*Notacanthus indicus* (Lloyd, 1909)	0.12
56	*Notacanthus* sp.	0.12
57	*Champsodon snyderi* (Franz, 1910)	0.10
58	*Cubiceps baxteri* (McCulloch, 1923)	0.09
59	*Nemichthys scolopaceus* (Richardson, 1848)	0.09
60	*Gavialiceps taeniola* (Alcock, 1889)	0.09
61	*Gadomus capensis* (Gilchrist & von Bonde, 1924)	0.08
62	*Melanocetus johnsonii* (Günther, 1864)	0.08
63	*Hypopleuron caninum* (Smith & Radcliffe, 1913)	0.08
64	*Gnathanodon speciosus* (Forsskål, 1775)	0.08
65	*Cottunculus* sp.	0.07
66	*Chauliodus sloani* (Bloch & Schneider, 1801)	0.07
67	*Chaunax pictus* (Lowe, 1846)	0.01
68	*Ogcocephalus* sp.	0.06
69	*Owstonia weberi* (Gilchrist, 1922)	0.07
70	*Chaunax* sp.	0.06
71	*Cubiceps* sp.	0.06
72	*Champsodon* sp.	0.05
73	*Halieutaea* sp.	0.04
74	*Rexea* sp.	0.04
75	*Zenopsis* sp.	0.04
76	*Gephyroberyx* sp.	0.01

represents the distance or similarity between clusters. The horizontal axis represents the objects and clusters (Figure 3).

In this study, there is no similarity observed between ~200 m depth zones and ~1000 m depth zones. We can see the five stations of 200 m depths form a single cluster and 1000 m depth stations are formed into another cluster with zero percentage similarity in the community structure. That means the stations of similar depth are in the same group. It shows the similarity of the similar depth stations in the community structure. Moreover, adjacent stations with the same depth are showing close similarity.

K-dominance plot

Figure 4 is a plot of the percentage cumulative abundance plotted against log species rank (Lambshead *et al*., 1983). It is a graphical method used for comparing diversity between samples. Note that the lower line has the higher diversity and that if the lines for two samples cross then they will tend to rank differently for different diversity indices.

K-dominance plots for the sites revealed that at the 200 m isobaths, the first 10 species that contributed total abundance of each station about 99% (S-10), 90% (S-2), 83% (S-7), 81% (S-4) and 81% (S-6) respectively. In the 1000 m, isobaths k-dominance plots revealed that the first 10 species that contributed total abundance at each station are 77% (S-5), 71% (S-3), 67% (S-1), 63% (S-8), 61% (S5).

K-dominance curves (Figure 5) for the two depth zones (~200 m and ~1000 m) were plotted. From this curve, in the ~200 m depth zone a single species contributes 40% of total abundance and 10 species contribute 83% of the total abundance. Probability of a single species contribution is 17% and the 10 species contribute 71% of the total abundance in the 1000 m depth zone. In the two extreme zones of the mesopelagic region, the ~1000 m depth zone is more diverse than the ~200 m depth zone.

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Table 3. Diversity indices of 10 sampling stations of the South-east Arabian Sea.

Sites (Depth)	Margalef's richness index (*d*)	Shannon diversity index (log e^2)	Pielou's evenness index (J')	Simpson diversity index ($1 - \lambda$).
S1-Cape (1000 m)	3.97	3.86	0.83	0.91
S1-Cape (200 m)	2.76	2.86	0.64	0.78
S3-TVM (1000 m)	3.43	3.59	0.79	0.87
S4-TVM (200 m)	3.08	1.62	0.34	0.49
S5-KLM (1000 m)	3.49	2.73	0.60	0.71
S6-KLM (200 m)	2.97	3.52	0.77	0.88
S7-COC (200 m)	3.45	3.72	0.83	0.92
S8-Ponnani (1000 m)	4.76	3.28	0.66	0.78
S9-Kannur (1000 m)	4.02	3.81	0.81	0.91
S-10-Kannur (200 m)	1.80	2.80	0.76	0.80

Table 4. Average diversity indices at different depth zones and its comparison with earlier study in the South-eastern Arabian Sea.

	Present study		Sudhakar *et al.* (2013)	
Diversity indices/depth	~200 m	~1000 m	100–300 m	1000–1200 m
Margalef's richness index (*d*)	2.79	3.93	3.30	3.2
Shannon index (log e^2)	2.90	3.45	2.05	2.11
Pielou's evenness index (J')	0.664	0.738	0.62	0.88
Simpson's diversity index ($1 - \lambda$)	0.772	0.834	NA	NA

DISCUSSION

In all, 76 species were identified and listed. Many species observed during the research expedition have not been included in the list because the present study focuses on ichthyofaunal diversity and assemblage. The reports on species checklist is one of the important tools to identify species diversity, especially in the deep-sea ecosystem. In the present study, diversity indices are comparatively higher at ~1000 m isobaths. Sudhakar *et al.* (2013) reported that species diversity increases with increase in depth up to 900 m in the South-eastern Arabian Sea. A similar phenomenon has been reported from the Gulf of Mexico (Bianchi, 1991; Powell *et al.*, 2003), Mediterranean Sea (Moranta *et al.*, 1998) and North Atlantic Ocean (Merrett *et al.*, 1991; Farina *et al.*, 1997). Classical diversity indices are helpful to measure the status of the diversity, and it can be used as a reference point for continuing studies, thus helping in the analyses of the status of the deep-sea ecosystem of this area.

Cluster analysis reveals the entirety of the different species assemblage and community structure in the two different depth zones. Diversity and species assemblages change according to depth. None of the species at 200 m are represented at 1000 m and the two depth zones (~200 and ~1000 m) are the two extremes of the mesopelagic realm. Currently the deep-sea bottom of the South-eastern Arabian Sea is not exploited for commercial fishing; these diversity values will be useful for future analyses if the area is exploited in the future.

The K-dominance plot of the 10 sampled stations of the South-eastern Arabian Sea is quite sigmoidal in shape. It

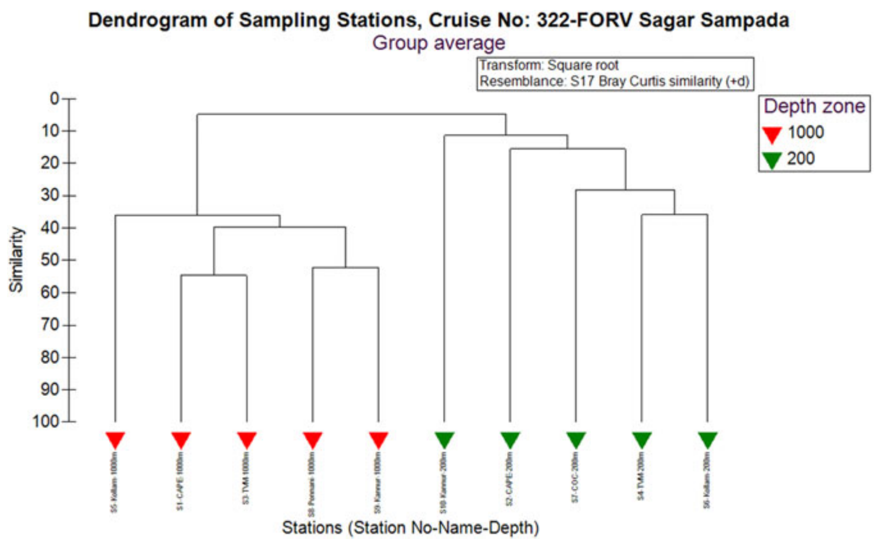

Fig. 3. Dendrogram of the results of running the species abundance data through the Group Average clustering algorithm.

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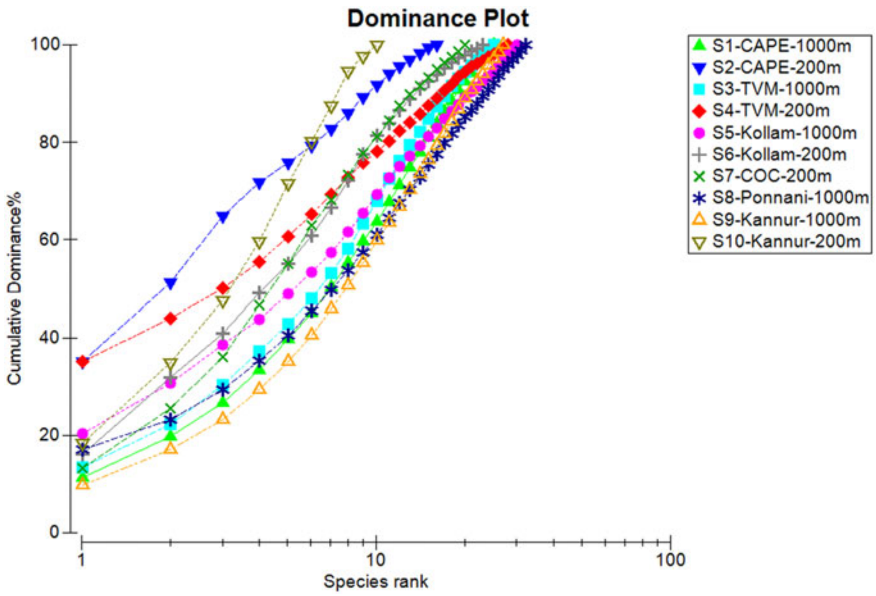

Fig. 4. K-dominance plot for the 10 stations of the South-eastern Arabian Sea.

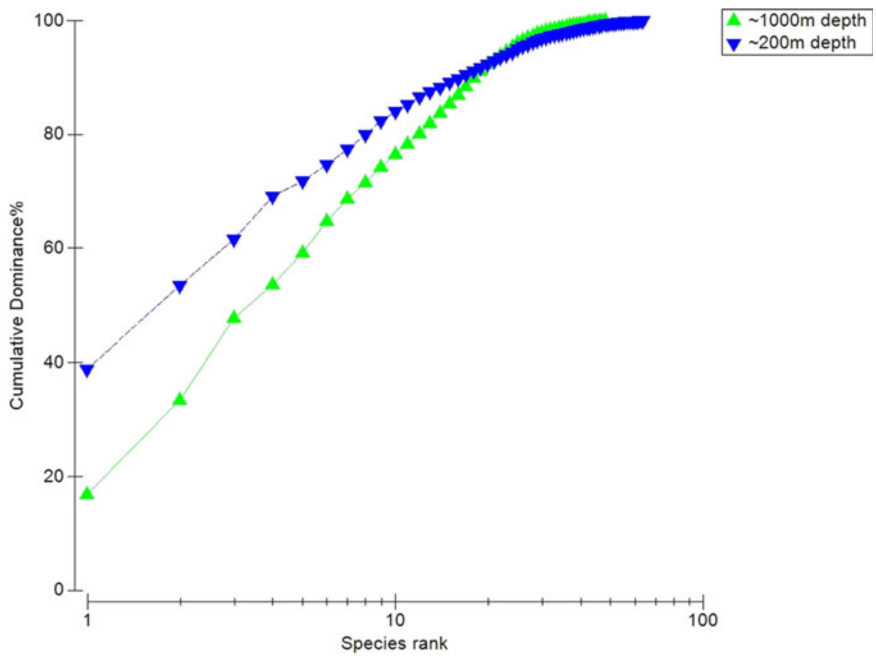

Fig. 5. K-dominance plot for the two depth zones of the South-eastern Arabian Sea.

reveals an undisturbed ecosystem in the deep waters of the study area. Bottom trawling operations in the region are limited to depths of 100–150 m. So the deep ecosystem is currently undisturbed by commercial trawlers. Dominance plot for the two different depth zones reveals that ~1000 m depth is more diverse than ~200 m depth.

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REFERENCES

Alcock A. (1899) *A descriptive catalogue of the Indian deep-sea fishes in the Indian Museum.* Enfield, NH: International Science Publisher, 211 pp.

Balachandran K., Menon N.G. and Pillai N.G.K. (1996) Scope for the exploitation and management of non-conventional fish resources

https://doi.org/10.1017/S0025315417001151 Published online by Cambridge University Press

from the distant waters of Indian EEZ. *Proceedings of the Fourth Indian Fisheries Forum, Cochin*, pp. 405–409.

Bianchi G. (1991) Demersal assemblages of the continental shelf and slope edge between the Gulf of Tehuantepec (Mexico) and the Gulf of Papagayo. *Marine Ecology Progress Series* 73, 121–140.

Clarke K.R. and Gorley R.N. (2006) *PRIMER v6: user manual/tutorial*. Plymouth: PRIMER-E, 192 pp.

Clarke K.R. and Warwick R.M. (2001) *Change in marine communities: an approach to statistical analysis and interpretation*, 2nd edition. Plymouth: Primer-E.

Eric P. and Benoit S.B. (2013) marmap: a package for importing, plotting and analyzing bathymetric and topographic data in R. *PLoS ONE* 8: e73051.

Eschmeyer W.N., Fricke R., Fong J.D. and Polack D.A. (2010) Marine fish diversity: history of knowledge and discovery (Pisces). *Zootaxa* 50, 19–50.

Eschmeyer W.N., Fricke R. and van der Laan R. (eds) (2016) Catalog of fishes: Genera, species, references. Online version, updated 1 December 2016. Internet publication, San Francisco (California Academy of Sciences). http://research.calacademy.org/research/Ichthyology/Catalog/fishcatmain.asp.

Farina A.C., Fereire J. and Gonzalez-Gurriran E. (1997) Demersal fish assemblages in the Galician continental shelf and upper slope (NW Spain): spatial structure and long-term changes. *Estuarine Coastal Shelf Science* 44, 435–454.

Froese R. and Pauly D. (eds) (2016) *FishBase*. World Wide Web electronic publication. http://www.fishbase.org.

Hashim M. (2012) Distribution diversity and biology of deep-sea fishes in the Indian EEZ. PhD thesis. Cochin University of Science and Technology, Cochin, India.

James P.S.B.R. and Pillai V.N. (1990) Fishable concentrations of fishes and crustaceans in the offshore and deep-sea, the exclusive economic zone of southwest coast of India. *Fishery Technology* 30, 102.

Jayaprakash A.A., Kurup B.M., Sreedhar U., Venu S., Thankappan D., Manjebrayakath H., Pachu V.A., Thampy P. and Sudhakar S. (2006) Distribution, diversity, length-weight relationship and recruitment pattern of deep-sea finfishes and shellfishes in the shelf-break area of Southwest Indian EEZ. *Journal of the Marine Biological Association of India* 48, 121–123.

Khan A., Murugesan S.M. and Lyla P.S. (2004) A new indicator macro invertebrate of pollution and utility of graphical tools and diversity indices in pollution monitoring studies. *Current Science* 87, 1508–1510.

Khan M., Zacharia P.U., Nandakumaran K., Mohan S., Arputharaj M.R., Nagaraja D. and Ramakrishnan P. (1996) Catch, abundance and some aspects of biology of deep-sea fish in the southeastern Arabian Sea. *Proceedings Asian Fisheries Science*, 617–629.

Lambshead P.J.D., Piatt H.M. and Shaw K.M. (1983) The detection of differences among assemblages of marine benthic species based on an assessment of dominance and diversity. *Journal of Natural History* 17, 859–974.

Magurran A.E. (2004) *Measuring biological diversity*. Oxford: Blackwell Publishing.

Margalef R. (1958) Information theory in ecology. *General Systems* 3, 36–71.

Mathew S. (2003) Deep sea fishing: towards diversified operations. *The Hindu Daily*, 6.1.2003.

Merrett N.R., Gordon J.D.M., Stehmann M. and Haedrich R.L. (1991) Deep demersal fish assemblage structure in the porcupine seabight (eastern North Atlantic): slope sampling by three different trawls compared. *Journal of the Marine Biological Association of the United Kingdom* 71, 329–358.

Moranta J., Steianescu C., Massuti E., Morales-Nin B. and Lloris D. (1998) Fish community structure and depth related trends on the continental slope of the Balearic Islands (Algerian basin, western Mediterranean). *Marine Ecology Progress Series* 171, 247–259.

Moratto T., Watson R., Pitcher T.J. and Pauly D. (2006) Fishing down the deep. *Fish and Fisheries* 7, 24–34.

Nair K.N.V. and Joseph K.M. (1984) Important observations on the deep-sea resources made during 1983–84. *Bulletin Fishery Survey of India* 13, 1–11.

Panicker P.A., Boopendranath M.R. and Syed Abbas M. (1993) Observations on deep-sea demersal resources in the exclusive economic zone of southwest coast of India. *Fishery Technology* 30, 102.

Pielou E.C. (1966) Species diversity and pattern diversity in the study of ecological succession. *Journal of Theoretical Biology* 10, 370–383.

Powell S.M., Haedrich R.L. and McEachran J.D. (2003) The deep-sea demersal fish fauna of the Northern Gulf of Mexico. *Journal of Northwest Atlantic Fisheries Science* 31, 19–33.

R Core Team (2016) *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. https://www.R-project.org/.

Shannon C.E. and Weaver W. (1949) *The mathematical theory of communication*. Urbana-Champaign, IL: University of Illinois Press.

Sivakami S. (1989) Observation on the demersal fishery resources of the coastal and deep-sea demersal resources in the Exclusive Economic Zone of India. *Proceedings of workshop on scientific results of FORV Sagar Sampada, 5–7 June, 1989, Cochin*. pp. 215–232.

Smith M.M. and Heemstra P.C. (1986) *Smith's sea fishes*. Berlin: Springer Verlag Publishers.

Sudhakar G.V.S., Sreedhar U. and Meenakumari B. (2013) Abundance, bathymetric distribution and diversity of deep sea demersal fin fish resources along the South-West Coast of India. *Indian Journal of Fisheries* 60, 1–6.

Turkmen G. and Kazanci N. (2010) Application of various biodiversity indices to benthic macoinvertebrate assemblages in streams of a national park in Turkey. *Review of Hydrology* 3, 111–125.

and

Venu S. and Kurup B.M. (2002) Distribution and abundance of deep-sea fishes along the west coast of India. *Fishery Technology. Society of Fisheries Technologists* 39, 20–26.

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