Indian J. Fish., 63(2) : 8-18, 2016
DOI: 10.21077/ijf.2016.63.2.45862-02

Effect of monsoon on coastal fish diversity of Goa: an example from the gillnet fishery

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ABSTRACT

The dynamics of fauna in coastal ecosystems are influenced by seasonal patterns in the oceanographic environment. It is well known that the monsoon along south-west coast of India influences the movement and spawning of fishes. Thus, they have direct effect on the richness, abundance and evenness of fish diversity in the ecosystem. This study investigates how the monsoon affects the commercial gillnet fishery along the coast of Goa. Fishing experiments were conducted in popular gillnet fishing grounds and the temporal pattern in diversity indices between October 2013 and September 2014 was assessed. A total of 124 fish species (40 families), 16 crustacean species (4 families) and 9 molluscan species (8 families) were recorded. The species diversity was found to be significantly different during the monsoon season and the species abundance distribution followed a geometric series during this period indicating signs of ecosystem perturbations. The economic and biological aspects of gillnet fishing in relation to the monsoon season in Goa are also discussed.

Keywords: Fish diversity, Goa, Monsoon, Species abundance

Introduction

Coastal ecosystems are complex adaptive systems composed of interconnected groups of living organisms and their habitats (Levin and Lubchenco, 2008). The seasonal reversal of winds in the Arabian Sea, termed as ‘south-west monsoon’ results in heavy precipitation along the west coast of India during June to September (Rao, 1976). The monsoon mediated environmental fluctuations in the coastal ecosystem affect the movement and spawning activities of aquatic species (James, 1992) and thus influence the diversity of fish species (Tremain and Adams, 1995). The coastal fauna, especially fish assemblages are historically being used as indicators of ecosystem health (Ujevic *et al.,* 2000; Carrasco *et al.,* 2003; Prego and Cobelo-Garcia, 2003). Fish assemblages often experience temporal variations in species diversity, in terms of richness (the number of species), abundance (the biomass of species) and evenness (the homogeneity of species across spatial and temporal scales). If the abundance is very high for a few species, the species diversity deviates away from evenness (Preston, 1948). Thus, the higher richness and evenness show rich diversity of the aquatic species in the coastal ecosystem. Several researchers have used numerical indices to measure the dynamics of richness (*e.g.* Margalef’s index), evenness (*e.g.* Heip’s index) and overall diversity (*e.g.* Shannon index), particularly for the assessment of seasonal patterns in fish diversity (Schooley, 1977; Blaber and Blaber, 1980; Gilmore, 1988; Tremain and Adams, 1995). Exploring the seasonal variation in species diversity will help to understand the effect of external perturbations on coastal ecosystems (De Ben *et al.,* 1990). The current investigations are based on the Siridao coast in the mouth of Zuari Estuary, one of the major estuaries of Goa opening to the Arabian Sea (Fig. 1). The margins of Zuari Estuary have dense mangrove vegetation filled with silt, clay and detritus transported by riverine influx from upper reaches. The marshy areas extend for a distance of 4 km and remain inundated during the high tide. The entire mudflats along with mangrove vegetation make the region highly productive, supporting large numbers of economically important fish species (Ansari *et al.,* 1995). Siridao has the maximum precipitation during the south-west monsoon accompanied by stormy weather, while quieter conditions prevail during the rest of the year (Ansari *et al.,* 1995).

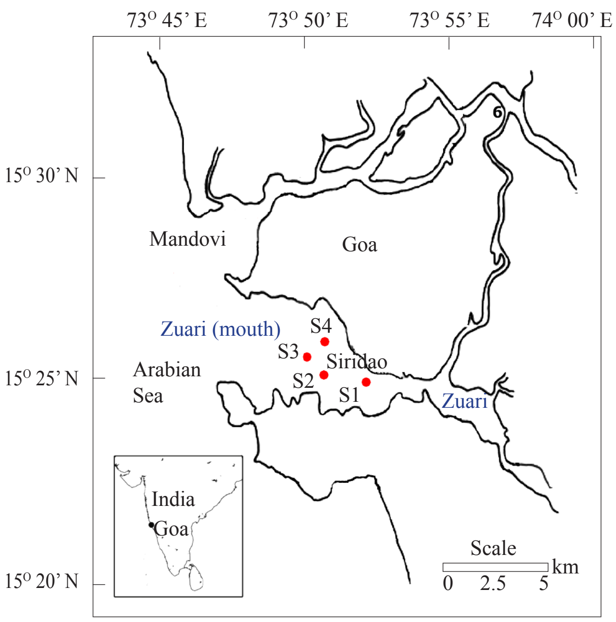

Fig. 1. Map showing the experimental fishing locations (S1, S2, S3, S4) along the Siridao coast of Goa

The entire coastal zone of Siridao has a bed of rocky patches (which makes it unsuitable for trawling) and hence gillnet fishery accounts for the majority of the landed catch. The Siridao region holds a medium fish landing centre which lands an average of 300 t of catch per year (Table 1; Anon., 2014). The gillnet fishery is a traditional subsistence activity along the Siridao coast with catches consisting of fish and shellfish groups (Anon. 2014). Seasonal fluctuations in the environment may have an impact on the fish diversity along the Siridao coast. The present study monitors the fish diversity of Siridao and attempts to understand the temporal changes in diversity indices that occur during the months of monsoon. Based on these results, we discuss the effect of monsoon on fish populations and the gillnet fishery of Goa.

Table 1. Siridao region: fisheries profile

Particulars	Details
Fishermen families	90
Fishermen population	548
Fishing crafts	Fibre glass
Gears used	Gillnets, seine nets and traps
Mesh size (mm)	30-120 (Gillnet), 15-40 (Seine net)
Average catch per boat per day (kg)	25-30
Average fish landings in an year (t)	300
Major species in fishery	Mackerel, sardines, white sardine, mullets, whitebaits, moustached anchovy, mullets, silverbellies, carangids, croakers, catfish, crabs, shrimps

Materials and methods

Sampling and data collection

Fishing experiments were conducted along the Siridao coast on a monthly basis to study the seasonal fish diversity between October 2013 and September 2014. A total of four spatial locations were chosen for fishing, after consulting researchers, fishermen and other stakeholders in the fishing industry, to locate regions that are commonly used for commercial gillnet operations (Fig. 1). A total of 36 fishing experiments were carried out, three each in a month, the day being selected randomly every 10 days. The experiments were carried out using hired commercial motorised fishing crafts. Bottom set gillnets of 30 mm mesh size (minimum legal mesh size for gillnet) having 400 m length (commonly used by the industry) were used for the whole experiment period. Siridao coast has a depth profile ranging from 3-5 m (Qasim and Sen Gupta, 1981) and hence the fishing experiments were carried out at 4 m average depth. The fishing experiments were set to operate for 2 h since most commercial gillnets are operated between 2-3 h of duration (Pillai *et al.,* 2000).

Fish and shellfish fauna collected during the study were identified to the genus and species levels. The fish species observed were categorised into different resource groups (Table 2) according to the classification given by ICAR-Central Marine Fisheries Research Institute (CMFRI, 2013). To classify and determine the effects of monsoon, we divided the months into three *viz.,* pre-monsoon (February to May), monsoon (June-September) and post-monsoon (October to January) seasons (Shamsan, 2008). Further, the species/resource group data were pooled across different seasons for evaluating the differences in their diversity indices.

Diversity indices

The resource group data were analysed using the diversity indices to measure the species abundance, richness and evenness in the ecosystem. Dominance index (D) (Simpson, 1949), Shannon Index (H) (Shannon and Weaver, 1948), Heip's Evenness Index (E) (Heip, 1974) and Margalef's Richness Index (M) (Clifford and Stephenson, 1975) were the diversity indices used in this study. All diversity indices were tested using ANOVA to determine whether they are significantly different between the seasons and the sites used for fishing experiments.

Percentage similarity index (PSI)

To compare the species composition between seasons, we computed the quantitative percentage similarity index

Table 2. Species obtained in the gillnet fishing experiments along Siridao coast off Goa

Group	Species	Family	Class	Group	Species	Family	Class
Barracuda	*Sphyraena jello*	Sphyraenidae	Pelagic	Croaker	*Otolithes cuvieri*	Sciaenidae	Demersal
Barracuda	*S. obtusata**	Sphyraenidae	Pelagic	Croaker	*O. argenteus*	Sciaenidae	Demersal
Bony breams	*Anodontostoma chacunda*	Clupeidae	Pelagic	Croaker	*Paranibea semiluctuosa*	Sciaenidae	Demersal
Bony breams	*Nematalosa nasus**	Clupeidae	Pelagic	Eel	*Congresox talabon**	Muraenesocidae	Demersal
Carangids	*Alepes kleinii**	Carangidae	Pelagic	Eel	*Muraenesox bagio*	Muraenesocidae	Demersal
Carangids	*A. melanoptera*	Carangidae	Pelagic	Eel	*M. cinereus*	Muraenesocidae	Demersal
Carangids	*A. kalla*	Carangidae	Pelagic	Flathead	*Rogadius pristiger*	Platycephalidae	Demersal
Carangids	*Atule mate*	Carangidae	Pelagic	Flathead	*Platycephalus indicus**	Platycephalidae	Demersal
Carangids	*Carangoides praeustus*	Carangidae	Pelagic	Grouper	*Epinephelus diacanthus*	Serranidae	Demersal
Carangids	*Scomberoides lysan*	Carangidae	Pelagic	Grunts	*Plectorhinchus gibbosus*	Haemulidae	Demersal
Carangids	*S. tol*	Carangidae	Pelagic	Pufferfish	*Lagocephalus wheeleri**	Tetraodontidae	Demersal
Carangids	*S. commersonnianus*	Carangidae	Pelagic	Pufferfish	*L. inermis*	Tetraodontidae	Demersal
Carangids	*Trachinotus mookalee*	Carangidae	Pelagic	Pufferfish	*Tetraodon fluviatilis*	Tetraodontidae	Demersal
Carangids	*Alectis ciliaris*	Carangidae	Pelagic	Silverbellies	*Leiognathus dussumieri*	Leiognathidae	Demersal
Carangids	*A. indicus*	Carangidae	Pelagic	Silverbellies	*L. bindus*	Leiognathidae	Demersal
Full beak	*Strongylura strongylura*	Belonidae	Pelagic	Silverbellies	*L. brevirostris**	Leiognathidae	Demersal
Golden anchovy	*Coilia dussumieri*	Engraulidae	Pelagic	Silverbellies	*L. blochii*	Leiognathidae	Demersal
Half beak	*Hyporamphus dussumieri*	Hemiramphidae	Pelagic	Silverbellies	*L. equulus*	Leiognathidae	Demersal
Half beak	*H. limbatus**	Hemiramphidae	Pelagic	Silverbellies	*L. splendens*	Leiognathidae	Demersal
Half beak	*Hemiramphus lutkei*	Hemiramphidae	Pelagic	Silverbellies	*L. daura*	Leiognathidae	Demersal
Horse mackerel	*Megalaspis cordyla*	Carangidae	Pelagic	Silverbellies	*Secutor insidiator*	Leiognathidae	Demersal
Mackerel	*Rastrelliger kanagurta*	Scombridae	Pelagic	Silverbiddies	*Gerres filamentosus**	Gerreidae	Demersal
Glassy perchlets	*Ambassis ambassis**	Ambassidae	Pelagic	Silverbiddies	*G. setifer*	Gerreidae	Demersal
Glassy perchlets	*A. gymnocephalus*	Ambassidae	Pelagic	Silverbiddies	*G. longirostris*	Gerreidae	Demersal
Drift fishes	*Drepane punctata*	Drepanidae	Pelagic	Snapper	*Lutjanus johnii**	Lutjanidae	Demersal
White pomfret	*Pampus argenteus*	Stromateidae	Pelagic	Snapper	*L. indicus*	Lutjanidae	Demersal
Moustached anchovy	*Thryssa malabarica*	Engraulidae	Pelagic	Rabbit fish	*Siganus canaliculatus*	Siganidae	Demersal
Moustached anchovy	*T. mystax**	Engraulidae	Pelagic	Sole	*Euryglossa orientalis*	Soleidae	Demersal
Moustached anchovy	*T. setirostris*	Engraulidae	Pelagic	Sole	*Pseudorhombus triocellatus*	Paralichthyidae	Demersal
Moustached anchovy	*T. hamiltonii*	Engraulidae	Pelagic	Sole	*P. arsius**	Paralichthyidae	Demersal
Mullets	*Liza macrolepis*	Mugilidae	Pelagic	Sole	*Solea* sp.	Soleidae	Demersal
Mullets	*L. parsia*	Mugilidae	Pelagic	Threadfin	*Polynemus heptadactylus*	Polynemidae	Demersal
Mullets	*L. tade*	Mugilidae	Pelagic	Threadfin	*Eleutheronema tetradactylum**	Polynemidae	Demersal
Mullets	*Mugil cephalus**	Mugilidae	Pelagic	Tiger perch	*Terapon jarbua**	Terapontidae	Demersal
Mullets	*Moolgarda cunnesius*	Mugilidae	Pelagic	Tiger perch	*T. theraps*	Terapontidae	Demersal
White sardine	*Escualosa thoracata*	Clupeidae	Pelagic	Tiger perch	*T. puta*	Terapontidae	Demersal
Long finned herring	*Opisthopterus tardoore*	Pristigasteridae	Pelagic	Tiger perch	*Pelates quadrilineatus*	Terapontidae	Demersal
Rainbow sardine	*Dussumieria acuta*	Dussumieriidae	Pelagic	Tongue sole	*Cynoglossus macrolepidotus**	Cynoglossidae	Demersal
Sand whiting	*Sillago sihama*	Sillaginidae	Pelagic	Tongue sole	*C. macrostomus*	Cynoglossidae	Demersal
Sardines	*Sardinella albella*	Clupeidae	Pelagic	Tongue sole	*C. dispar*	Cynoglossidae	Demersal
Sardines	*S. gibbosa*	Clupeidae	Pelagic	Tongue sole	*C. puncticeps*	Cynoglossidae	Demersal
Sardines	*S. longiceps**	Clupeidae	Pelagic	Tongue sole	*Paraplagusia bilineata*	Cynoglossidae	Demersal
Scat	*Scatophagus argus*	Scatophagidae	Pelagic	Blind goby	*Trypauchen vagina*	Gobiidae	Demersal
Shads	*Ilisha filigera*	Pristigasteridae	Pelagic	Rays	*Himantura uarnak*	Dasyatidae	Demersal
Shads	*I. megaloptera*	Pristigasteridae	Pelagic	Rays	*H. imbricata**	Dasyatidae	Demersal
Shads	*I. melastoma*	Pristigasteridae	Pelagic	Rays	*H. fluviatilis*	Dasyatidae	Demersal
Shads	*Tenualosa toli**	Clupeidae	Pelagic	Rays	*Aetobates narinari*	Myliobatidae	Demersal
Whitebaits	*Encrasicholina devisi*	Engraulidae	Pelagic	Toad fish	*Amphichthys cryptocentrus*	Batrachoididae	Demersal
Whitebaits	*Stolephorus commersonii**	Engraulidae	Pelagic	Tripod fish	*Triacanthus biaculeatus*	Triacanthidae	Demersal
Whitebaits	*S. indicus*	Engraulidae	Pelagic	Crabs	*Charybdis lucifera*	Portunidae	Crustacean
Ribbonfish	*Trichiurus lepturus*	Trichiuridae	Pelagic	Crabs	*C. natator*	Portunidae	Crustacean

Group	Species	Family	Class	Group	Species	Family	Class
Ribbonfish	*Lepturacanthus savala**	Trichiuridae	Pelagic	Crabs	*Portunus sanguinolentus*	Portunidae	Crustacean
Seerfish	*Scomberomorus commerson*	Scombridae	Pelagic	Crabs	*P. pelagicus**	Portunidae	Crustacean
Bamboo shark	*Chilloscyllium griseum*	Hemiscyllidae	Demersal	Crabs	*Scylla serrata*	Portunidae	Crustacean
Big Jawed Jumper	*Lactarius lactarius*	Lactariidae	Demersal	Crabs	*S. tranquebarica*	Portunidae	Crustacean
Bream	*Acanthopagrus berda*	Sparidae	Demersal	Crabs	*Matuta lunaris*	Matutidae	Crustacean
Catfish	*Arius arius*	Ariidae	Demersal	Penaeid Shrimp	*Fenneropenaeus indicus**	Penaeidae	Crustacean
Catfish	*A. caelatus*	Ariidae	Demersal	Penaeid Shrimp	*Marsupenaeus japonicus*	Penaeidae	Crustacean
Catfish	*A. dussumieri*	Ariidae	Demersal	Penaeid Shrimp	*Metapenaeus affinis*	Penaeidae	Crustacean
Catfish	*A. jella*	Ariidae	Demersal	Penaeid Shrimp	*M. brevicornis*	Penaeidae	Crustacean
Catfish	*A. platystomus**	Ariidae	Demersal	Penaeid Shrimp	*M. dobsoni*	Penaeidae	Crustacean
Catfish	*A. subrostratus*	Ariidae	Demersal	Penaeid Shrimp	*M. monoceros*	Penaeidae	Crustacean
Catfish	*A. thalassinus*	Ariidae	Demersal	Penaeid Shrimp	*Parapenaeopsis stylifera*	Penaeidae	Crustacean
Catfish	*A. venosus*	Ariidae	Demersal	Stomatopods	*Lysiosquilla* sp.	Squillidae	Crustacean
Catfish	*A. maculatus*	Ariidae	Demersal	Stomatopods	*Oratosquilla nepa**	Squillidae	Crustacean
Croaker	*Dendrophysa russelli*	Sciaenidae	Demersal	Window pane oyster	*Placuna placenta*	Placunidae	Molluscan
Croaker	*Johnieops borneensis*	Sciaenidae	Demersal	Cephalopod-squid	*Uroteuthis (Photololigo) duvaucelii**	Loliginidae	Molluscan
Croaker	*Johnieops sina*	Sciaenidae	Demersal	Indian squid	*Loliolus investigatoris*	Loliginidae	Molluscan
Croaker	*Johnius macrorhynus**	Sciaenidae	Demersal	Spineless cuttlefish	*Sepiella inermis*	Sepiidae	Molluscan
Croaker	*J. belangerii*	Sciaenidae	Demersal	Gastropod	*Bursa* sp.	Bursidae	Molluscan
Croaker	*J. dussumieri*	Sciaenidae	Demersal	Gastropod	*Hemifusus* sp.*	Melongenidae	Molluscan
Croaker	*Nibea albida*	Sciaenidae	Demersal	Gastropod	*Tibia curta*	Rostellariidae	Molluscan
Croaker	*N. soldado*	Sciaenidae	Demersal	Gastropod	*Telescopium* sp.	Potamididae	Molluscan
Croaker	*Nibea.* sp.	Sciaenidae	Demersal	Gastropod	*Natica* sp.	Naticidae	Molluscan
Croaker	*Otolithes ruber*	Sciaenidae	Demersal				

*Indicates the dominant species in the corresponding group, single species groups are not marked

(PSI) (Whittaker and Fairbanks, 1958). This index reflects the similarity in percentage abundance of different species between seasons. The PSI close to 100 indicates the highest similarity. The index is computed from the following equation.

$$PSI = 100\,(1.0 - 0.5\sum|P_{iA} - P_{iB}|) \quad (1)$$

where 'P_{iA}' is the proportion of the i^{th} species in season A and 'P_{iB}' is the proportion of the i^{th} species in season B. After obtaining the PSI values, Wilcoxon's signed rank test (T_S) was used to statistically examine whether the difference in species composition between seasons are significant or not. If T_S >1.96 at 5% level of confidence ($p<0.05$), this indicates a significant difference in species composition between the seasons.

Species abundance distributions

The number of samples obtained for each species during fishing experiments was considered as their relative abundance in the ecosystem. Statistical models make assumptions about the probability distributions of species abundance in an ecosystem (Taylor *et al.,* 1976). In the present study, we used four distribution models namely broken stick, geometric, log-series and log-normal models for comparing the species abundance between seasons (May, 1975).

Broken-stick model: This species abundance distribution is given by the probability density function:

$$\varphi_y = Se^{-Sy} \quad (2)$$

In this model, a limiting resource is compared with a stock, broken in 's' parts at 's-1' randomly located points. The length of the parts is taken as representative for density of the 's' species subdividing the limiting resources if 's' species are ranked according to abundance. Expected abundance of species 'i', N_i is given by:

$$E(N_i) = \frac{1}{s}\sum\frac{s}{x} = 1\frac{1}{x} \quad (3)$$

Geometric series: This distribution assumes that a species pre-empts a fraction 'k' of a limiting resource, a second species the same fraction of k of the remainder and so on. If the abundances of species are proportional to their share of resource, the ranked abundance list is given by a geometric series as follows*:*

$$k, k(1-k), \ldots, k(1-k)^{(s-2)}, k(1-k)^{(s-1)} \quad (4)$$

where 's' is the number of species in the sample. It yields a straight line on a plot of log (abundance) against rank.

Log-series distribution: The log-series is used to describe species abundance distributions in large collections. The expected number of species with 'r' individuals, E_r is given by:

$$E_r = \alpha \frac{x^r}{r} \quad \text{.......} (5)$$

where, r =1, 2, 3... α (>0), is a parameter independent of the sample size for which 'X' (0<X<1) is the representative parameter. The parameters 'α' and 'X' can be estimated by maximum likelihood method.

Log-normal distribution: The log-normal distribution for species abundance distributions is assumed in natural systems because of the multiplicative interaction effect of independent environmental factors on species abundance. The probability density function species abundance (y), $\psi_{(y)}$ is given by:

$$\varphi_y = \frac{1}{y\sqrt{2\pi V_z}} \exp\left[\frac{-(\text{Iny} - \mu_z)^2}{2V_z}\right] \quad \text{.......}(6)$$

$$\mu_y = \exp\left[\mu_z + \frac{V_z}{2}\right] \quad \text{.......}(7)$$

$$V_y = (\exp(V_z) - 1)\exp(2\mu_z + V_z) \quad \text{.......}(8)$$

where 'μ_z' and 'V_z' are the mean and variance of z [=ln(y)].

The broken-stick model is normally used as a test null model which assumes too even distribution of individuals over species (Frontier, 1985). The communities in disturbed environments follow the geometric series with uneven and high dominance for a few species (Whittaker, 1972). The log-series model assumes observed species abundance as a result of immigration, emigration, birth and death processes, and not by competition, predation or other specific biotic interactions (Casewell, 1976). The log-normal model consider both intra- and inter-specific interactions with a normality assumption of species abundance distribution (May, 1975).

To fit the species distribution models, the abundances were first log transformed using equation (9):

$$Y = \log(X+1) \quad \text{.......}(9)$$

where 'Y' is the log transformed abundance, 'X' is the absolute abundance of the species and 'X+1' was used to accommodate the zero observations. The log transformed abundance data was ranked from '1' to 's' (the total number of species) in the descending order to evaluate the pattern of seasonal differences in the species abundance. The model fitting was carried out using PAST software (Hammer *et al.,* 2001) and the goodness of fit was examined for the data in each season using Chi-square test at 5% level of significance.

Results and discussion

A total of 149 species comprising 124 finfish species (pelagic - 53, demersal - 71), 16 crustacean species and 9 molluscan species were collected during the study (Table 2). There was no significant difference in the diversity indices between different sites used for experimental fishing (Table 3). This could be because of their proximity indicating that similar habitats prevail in this region. Therefore, the data from all fishing sites were pooled together for further analysis. However, the diversity indices were significantly different for seasons (Table 3). Hence the diversity of fish species is discussed based on their seasonal differences.

Seasonal fluctuations in diversity indices

The study revealed that the richness and evenness indices were least during the monsoon season (Fig. 2). However, some species are tolerant enough to survive or cope with such environments prone to disturbances. This is clearly evident from dominance index (inverse of being diverse) where the values were highest during the monsoon period showing the dominance of some monsoon tolerant fish species. By the end of monsoon, the diversity of fish species eventually increased towards post-monsoon and thereafter to the pre-monsoon season (Fig. 2). The highest number of fish species was found during the pre-monsoon period (Fig. 2). The Shannon index and evenness index also indicated highest values during the pre-monsoon period (Fig. 2).

Seasonal differences in species abundances

The species abundance for different seasons is presented in Fig. 3, taking into account all those species with percentage abundance >5% of the catch. The abundance of commercial pelagic groups such as white sardine, whitebaits, mackerel, moustached anchovy, mullets, sardines, bigjawed jumper, silverbellies,

Table 3. ANOVA results on comparison of biodiversity indices across four different sampling stations and seasons

Variable	Station (mean sum of squares)	Season (mean sum of squares)
Dominance Index (D)	0.0002^{NS}	0.014^{**}
Shannon Index (H)	0.024^{NS}	5.75^{**}
Evenness Index (E)	0.001^{NS}	0.15^{**}
Margalef's Index (M)	3.15^{NS}	67.61^{**}

**significant at 1% level, ^{NS}not significant, All indices were significantly different between seasons with R-square value greater than 0.9

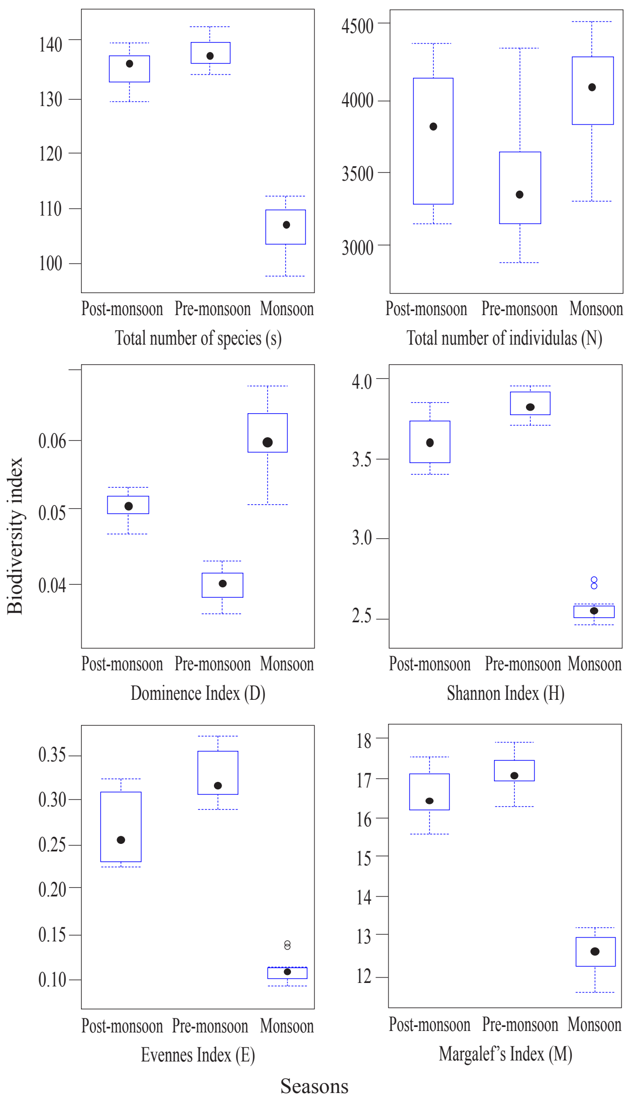

Fig. 2. Box plot of diversity indices observed during different seasons

stomatopods and penaeid shrimps were high during the monsoon season (Fig. 3). However, comparatively fewer species groups were abundant during the post-monsoon (carangids and bony breams) and pre-monsoon seasons (shads and crabs). Since the dominance index was high during the monsoon season, majority of the fish catch comprised species with high relative abundance. During pre-monsoon and post-monsoon periods, only a few species were abundant due to high species diversity and evenness. Therefore, the species diversity was low during the monsoon season. Thus, both the diversity indices and absolute abundance agree with each other on their differences during the monsoon season.

Seasonal differences in species compositions

The PSI was calculated to measure the similarity in species composition between two seasons (Table 4). The PSI values were 69.8% (monsoon and pre-monsoon), 71.28% (monsoon and post-monsoon) and 86.71% (post-monsoon and pre-monsoon) for different pairs of seasons. The PSI obtained for monsoon was significantly different from other seasons, indicating a substantial difference in species composition (Table 4). However, there was no significant difference between the PSI of post-monsoon and pre-monsoon seasons (Table 4). This result again complements our observations on species diversity and abundance during the monsoon season.

Table 4. The seasonal comparison of Percentage Similarity Index (PSI)

Season	Monsoon	Pre-monsoon
Monsoon	100	
Pre-monsoon	69.8^{*} (3.42)	
Post-monsoon	71.28^{*} (3.15)	86.71^{NS} (0.89)

*significantly different at 5% level, ^{NS}not significantly different, T_S values are given in parentheses

Performance of species abundance distribution models

A qualitative visual assessment on shape of species abundance curves shows that the species abundance follows a log-normal distribution during all seasons (Fig. 4). However, the species abundance curve for monsoon season appears distinct from pre-monsoon and post-monsoon seasons (Fig. 4). The abundance of species during different seasons were compared for their fitness to different probability distributions (Table 5). A quantitative assessment using chi-square test showed that the species abundance during monsoon season fitted better to a geometric series while for other seasons, it followed a log-normal distribution (Table 5).

The monsoon, post-monsoon and pre-monsoon seasons are characterised by unique changes in the current patterns, river discharges and temperature along the coastal regions (Shirodkar *et al.,* 2012). This induces changes in physico-chemical properties of coastal systems (Pradhan *et al.,* 2009).

Seasons vs. diversity

It has been reported that the dissolved oxygen (DO) fluctuates during the monsoon season due to turbulent river discharge (Shirodkar *et al.,* 2012). This could be the reason why species richness and evenness was low during the monsoon period. Also the most abundant resource groups during monsoon were the pelagic species which are relatively less impacted by fluctuating DO as they occupy the surface waters where oxygen transfer takes place continuously from the atmosphere. When compared to monsoon, comparatively stable values of DO will exist during the post-monsoon and pre-monsoon seasons (Shirodkar *et al.,* 2012; Sreekanth *et al.,* 2015). Due to upwelling during the monsoon season, the nutrient influx will also get utilised during the post-monsoon

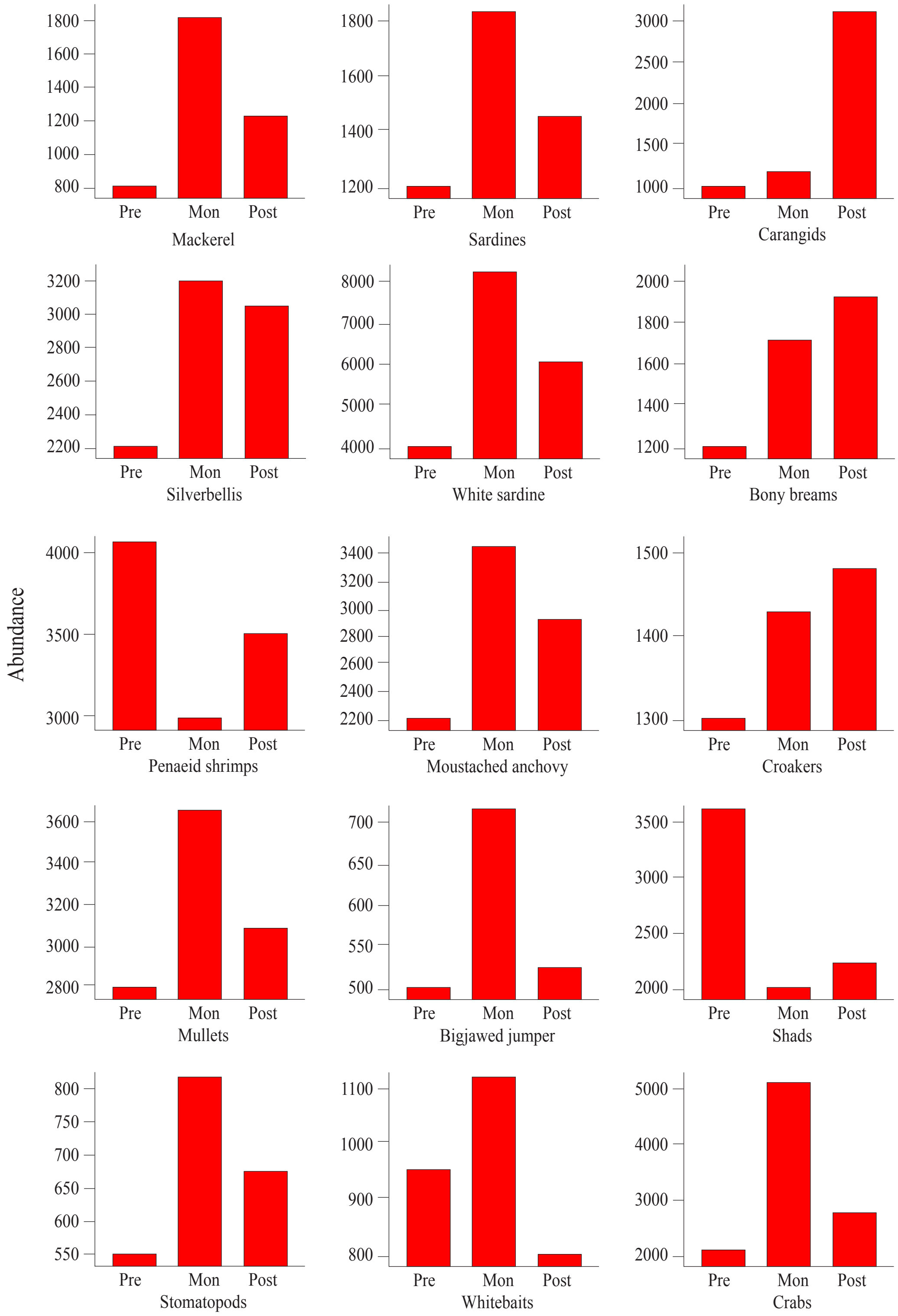

Fig. 3. The seasonal abundance (in numbers) of various resource groups observed during the present study. Pre: Pre-monsoon, Mon: Monsoon, Post: Post-monsoon

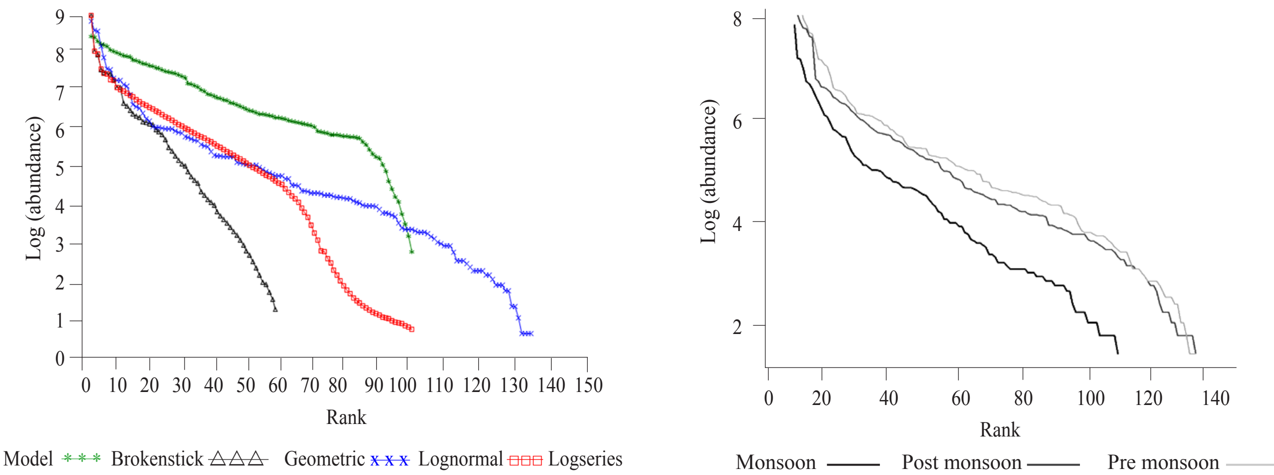

Fig. 4. Log converted seasonal species abundance plot. (a) hypothetical species abundance curves representing different distribution models and (b) observed species abundance curves for different seasons in the present study. (*The graphs were generated using the 'PROC SGPLOT' procedure of SAS software* (*SAS Institute, 2012*))

Table 5. Species abundance fitted for distribution models

Model	Monsoon		Post-monsoon		Pre-monsoon	
	Parameters	Chi-square	Parameters	Chi-square	Parameters	Chi-square
Geometric	k=0.0543	9894.2**	k=0.04148	784.5NS	k=0.0426	685.34NS
Log-series	alpha=15.31, X=0.986	95.21NS	alpha=16.71, X=0.975	34.28NS	alpha=17.42, X=0.994	42.31NS
Broken-stick		96.2NS		363.3NS		268.4NS
Log-normal	Mean=1.498, Var=0.625	14.12NS	Mean=1.865, Var=0.605	3.75**	Mean=1.792, Var=0.616	2.42**

**fitted with the model, NSnot fitted with the model, The null hypothesis assumed there is no significant difference between the distribution model and the observed species abundances

period resulting in stable chlorophyll content and primary productivity. Hence, this will enhance the fisheries resources during the post-monsoon season (Madhupratap *et al.,* 2001). This is clearly observed in our results *i.e.,* an increase in the number of species, Shannon index, Heip's evenness index and Margalef's index during the post-monsoon season.

In pre-monsoon, the temperature starts increasing and many environmental parameters such as solar radiation, DO, nutrients and primary productivity will be at an optimum level for spawning and reproductive activities. This triggers the monsoon intolerant fish species to migrate towards the inshore region, which thus leads to more diverse as well as evenly distributed taxonomic groups in the ecosystem (Madhupratap *et al.,* 2001; Shirodkar *et al.,* 2012). The Shannon index, Heips evenness index and Margalef's index were highest during the pre-monsoon season in our study. This explains that the pre-monsoon period is expected to have species groups with rich diversity along the Siridao coast.

A comparison of species abundance curves showed that the brokenstick model did not fit to the species abundance in any season. This was expected because it assumes an even distribution of individuals over species which is rare to occur (Frontier, 1985). The communities in harsh or disturbed environments follow the abundance of species in a geometric series with uneven and high dominance for few species (Whittaker, 1972). The south-west monsoon is a disturbed phase which creates turbulence and disturbance in the coastal ecosystems (Madhupratap *et al.,* 2001). This disturbance in the monsoon season might be a reason for fitting of species abundance curve to geometric series in the current study. The log-series distribution has been fitted for a good number of communities previously (Williams, 1964; Kempton and Taylor, 1974) but, they are less flexible in comparison to log-normal models in accomodating species with high abundance values. Since the log-normal distribution considers the interaction of a large number of independent environmental factors on species abundance patterns (May, 1975), this was found conceptually a better representational model for communities in pre-monsoon and post-monsoon seasons as they follow calm and undisturbed environments (Preston, 1948).

Impact of monsoon on gillnet fishery

In monsoon season, the richness and evenness of fish species will be decreased in coastal ecosystems due to low salinity by increased freshwater discharge from the rivers (Marais, 1982; Claridge *et al.,* 1986; Sreekanth *et al.,* 2015). Moreover, during this season, the coastal fish species will move offshore from the inshore regions (Ansari *et al.,* 1995). Thus the coastal gillnet fishery will be affected by this movement, with a reduction of fish diversity in the landed catch. The low value pelagic fish groups constitute the major catch during the monsoon season (James, 1992) and the economic benefit is comparatively less for the fishermen. However, there will be a recession of flood water after the monsoon season and marine conditions will be re-established along the coastal regions. Hence, the coastal species return to inshore waters during the post-monsoon and pre-monsoon seasons. As a result, the fish diversity in gillnet catches will increase with high value diverse demersal fish species (Legendre and Demus, 1984; Krishnan Kutty, 1985). This helps the fishermen to get better economic benefit during post-monsoon and pre-monsoon seasons.

Impact of monsoon on population biomass

Monsoon plays a significant role in the ecological cycle and productivity of the sea. The upwelling phenomenon as a result of monsoon winds is important for replenishing the nutrients in the surface layers towards the end of monsoon or after monsoon (James, 1992). Heavy rainfall during monsoon also reduces the surface temperature and salinity of inshore waters. Many important pelagic species are known to breed during this period along the west coast of India (Qasim, 1973). Environmental factors like low salinity, low temperature and nutrient rich surface waters during monsoon induce the primary productivity of coastal ecosystem and thereby, the plankton biomass which serve as a food item particularly for the larvae and juveniles of pelagic fish species (Subrahmanyan, 1967). This also underlines the fact that a high concentration of pelagic species groups was observed during the monsoon season in the present study. Hence it is inferred that the monsoon season would support the replenishment and sustenance of certain fish groups that are mostly pelagic in nature.

Limitations and future study

The important limitation of the present study is the lack of temporal data on environmental and oceanographic parameters. This would have helped, considering their compounding effects on diversity indices of the gillnet fishery. This is an important research direction to be addressed by future investigations. Although the number of sampling sites was limited in this study the sites in the mouth of Zuari Estuary represent an important coastal ecosystem of Goa where major commercial gillnet operations are carried out. This is also the first report on diversity investigations that has been conducted to determine the effect of monsoon on commercial gillnet fisheries. The results in this study quantify the seasonal pattern in fish diversity and hence this can be used as a reference period for future research at Siridao coastal ecosystem.

Acknowledgements

This study was carried out with scientific and technical support from ICAR-Central Institute of Fisheries Education, India. We express our heartfelt thanks to several research scholars (Department of Fisheries and Goa University) and fishermen along the Siridao coast for their kind cooperation with the fishing experiments, in particular, Mr. Sanjay Perera, (Head of Tiswadi Fishermen Association, North Goa) who provided assistance in site selection and sampling. The authors are grateful to the Director and other faculty members of ICAR-Central Coastal Agricultural Research Institute, Goa.

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Date of Receipt : 12.01.2015
Date of Acceptance : 02.03.2016