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On the persistent occurrence of potential fishing zones in the southeastern Arabian Sea

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Potential Fishing Zone (PFZ) advisory maps released by the INCOIS (Ministry of Earth Sciences, Government of India) during 2003-07 were analyzed for their frequency of occurrence and persistence. This analyses clearly indicates that the nearshore regions of the Arabian Sea off Kerala with depths less than 50 m occurred more in the PFZ advisory maps than the mid continental shelf region and the continental slope. Northen regions of Kerala had persistent PFZ areas especially in the region between Calicut and Kannur. Relatively high river discharges in the area and presence of high nutrient content in the discharges because of high mangrove afforestation are likely causes for the persistent occurrence of PFZs in these regions.

[Keywords: Potential fishing zones, Arabian Sea, Continental shelf and slope, River discharge, Mangroves]

Introduction

Coastal Zone Colour Scanner (CZCS) and Advanced Very High Resolution Radiometer (AVHRR) data were used to understand the relationship between chlorophyll and Sea Surface Temperature (SST)[1] and this in turn were used to make fishery forecasts[2]. Globally, the potential use of satellite imagery was recognized especially in the Northeastern Pacific fisheries[3] and in the Japanese fisheries[4]. In India, the Potential Fishing Zones (PFZ) forecasts were started during 1989-90 using NOAA AVHRR derived SST[2]. With the launch of Indian Remote Sensing Satellite (IRS P4) on May 26, 1999, the Ocean Colour Monitor (OCM) began to provide data on chlorophyll concentration[5]. It was observed that ocean colour features coincided with thermal boundaries at some locations indicating that physical and biological processes are closely coupled at these locations. Also, the OC features which are related to the primary productivity were found to be strongly related with SST. Based on satellite imageries, locations of special oceanic processes (SOPs) like eddies, fronts, rings and meanders could be identified based on a bio-optical algorithm[6,7], and considering the increased biological productivity of such areas it was inferred that these can be demarked as regions where increased fish catches can be obtained. Accordingly, these locations of SOPs began to be marked as lines or curves on base maps of specific regions and disseminated to the end users as Potential Fishing Zone (PFZ) advisories[5,8].

The PFZ advisories generated from satellite retrieved SST and chlorophyll were validated with the availability as well as abundance of pelagic fishes off the coast of Gujarat[9] and other regions in India[7]. Cholorophyll content of seawater depends largely on phytoplankton abundance which in turn fluctuates with the availability of nutrients and other physical and chemical parameters of the environment. Chlorophyll *a*, the primary photosynthetic pigment in the phytoplankton, absorbs relatively more blue and red light than green and the spectrum of back scattered sunlight of colour of the ocean progressively shifts from deep blue to green as the concentration of phytoplankton increases[10,11]. Recently, detailed studies on the formation of oceanographic processes in Northern Arabian Sea has clearly indicated that locations of cyclonic eddies and rings occur are more

productive than locations where anticlyclonic eddies occur and these areas are classified as low productive and were compared to biological deserts[12].

Oceanographic changes taking place in the southeastern Arabian sea off Kerala has been extensively studied during the latter half of last century through ship-based oceanographic surveys, and of the several factors investigated, upwelling was the most studied[13,14]. These studies have indicated that upwelling along Kerala coast especially in the northern part is intense and that it brings in the nutrient rich deep water to the surface making the region more productive. Later, as a part of Indian Joint Global Ocean Flux Studies (JGOFS), the significance of winds in controlling the upwelling along west coast was established[15]. Now with the application of remote sensing, the biologically productive areas are identified and indicated in the PFZ advisories.

While attempting to relate the PFZ locations and the fish catches along Kerala coast, it is observed that some regions of the coastal waters frequently occur as PFZs. This prompted us to investigate further and find out if there are areas where PFZs occur regularly and is there any relationship between depth, latitude and months and the PFZs. PFZ advisories generated and released by INCOIS during the period 2003 to 2007 were utilised for this study. An attempt is also made to find the reasons for the persistent occurrence of PFZ in certain regions in the Arabian Sea off Kerala.

Materials and Methods

Fishing area off Kerala within (Latitude 7° to 13°N; longitude 74° to 77°30'E) was divided into 18 Zones (one degree grid) starting from Zone 1 in the region off Kasargod and concluding in Zone 17 in the southern part of Kerala. Each Zone was further divided to 16 sub-grids (A to P; area of each grid 225 nm^2; Table 1). Based on depth, the grids were classified into three categories namely nearshore (NS; less than 50 m); mid continental shelf (MS; 50 to 200 m depth) and continental slope (CS; greater than 200 m depth). Of the 232 grids, NS had 39 (17%), MS had 46 (20%) and CS had 147 (63%) respectively.

For this investigation, 169 advisories released by INCOIS during the period 2003 to 2007 (5 years) were used. The curved lines marking on the PFZ advisory chart are locations where the productivity is high due to SOPs such as cyclonic eddies, rings, meanders and fronts which are made based on the satellite imageries. Base map with zones and sub-grids was superimposed on the PFZ advisory charts and potential fishing locations as indicated by the lines in the chart coinciding with the grids were recorded. Each occurrence in a grid was considered as a 'hit' (a sample advisory is shown in Fig.1). For example, in Zone 3, grids D, H, L. J, K, P, M, N, and O have got PFZs curves/lines running through them and each grid would score a hit. Multiple hits are also possible in a grid, as in Zone 6, grid K.

The number of PFZ hits on each grid based on the advisories were summed and from this the number of hits in a zone for each month and in the specific area categories were estimated. Grids with maximum

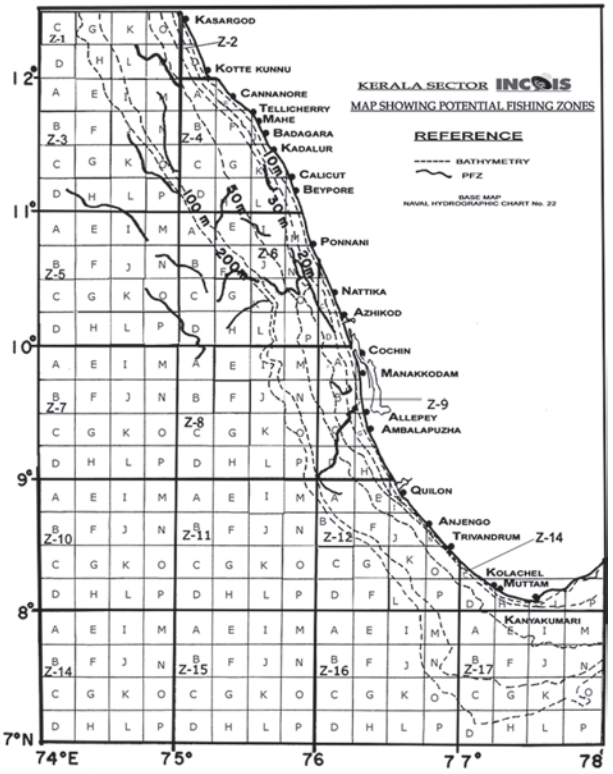

Fig.1–A sample map of PFZ advisory released by INCOIS showing curved lines indicating PFZs in different zones and grids in the Arabian Sea off Kerala.

Table 1–Details of zones and grids with PFZ hits during 2003-2007 off Kerala coast with adjacent fish landing centres

Latitude °N	Longitude °E	Zone	No of grids in different depth categories			Total grids	Total no. of PFZ hits	Main fish landing centres
			NS	MS	CS			
12 to 13	74 to 75 15	Zone 1	5	6	5	16	752	Kasargod, Kottekunnu
12 to 1230	74 to 75 15	Zone 2	2	0	0	2	143	Kasargod, Kottekunnu
11 to 12	74 to 75	Zone 3	0	5	11	16	255	Kannur, Tellicherry, Mahe, Badagara, Kadalur, Calicut, Beypore
11 to 12	75 to 75 50	Zone 4	9	3	0	12	893	Kannur, Tellicherry, Mahe, Badagara, Kadalur, Calicut, Beypore
10 to 11	74 to 75	Zone 5	0	0	16	16	140	Ponnani, Nattika, Azhikode
10 to 11	75 to 76	Zone 6	6	3	7	16	802	Ponnani, Nattika, Azhikode
10 to 11	76 to 76 15	Zone 6’	3	0	0	3	168	Ponnani, Nattika, Azhikode
9 to 10	74 to 75	Zone 7	0	0	16	16	68	Kochi, Manakkodam, Alleppey, Ambalapuzha
9 to 10	75 to 76	Zone 8	0	5	11	16	268	Kochi, Manakkodam, Alleppey, Ambalapuzha
9 to 10	76 to 76 30	Zone 9	7	1	0	8	523	Kochi, Manakkodam, Alleppey, Ambalapuzha
8 to 9	74 to 75	Zone 10	0	0	16	16	42	Kollam, Anjengo, Trivandrum, Kolachal, Muttam
8 to 9	75 to 76	Zone 11	0	0	16	16	122	Kollam, Anjengo, Trivandrum, Kolachal, Muttam
8 to 9	76 to 77	Zone 12	3	8	4	15	391	Kollam, Anjengo, Trivandrum, Kolachal, Muttam
8 to 9	76 to 76 30	Zone 13	2	0	0	2	30	Kollam, Anjengo, Trivandrum, Kolachal, Muttam
7 to 8	74 to 75	Zone 14	0	0	16	16	1	
7 to 8	75 to 76	Zone 15	0	0	16	16	10	
7 to 8	76 to 77	Zone 16	0	3	13	16	33	
7 to 8	77 to 78	Zone 17	2	12	0	14	10	
		Total	39	46	147	232	4651	
		% of total	17	20	63			
		Area (nmi^2)	3782	4461	14256	52200		
		No. of hits	2682	994	955	4651		

number of hits for the entire period were considered as persistent areas where PFZs occur.

'Spread' of the PFZ was evaluated based on the occurrence of the same in different grids and if more zones are covered, the better the spread of the PFZ. Latitude-wise occurence of hits was also estimated for the areas between latitudes 7-8°N, 8-9°N, 9-10°N,10-11°N and 11-12°N. It is also attempted to relate (Pearson correlation; SPSS version,13) mean annual latitude-wise river dischargedata of Kerala sourced from Basak[16] with PFZ hits.

Results and Discussion

In general, it was observed that the number of PFZ advisories were high during November to March ranging between an average of 6 to 8 per month, highest being in February and December (Fig. 2). During this 5 year period, advisories for the months of June, August and September were received only during the year 2007. In July no advisories were received and this is mainly due to the cloud cover which hinders satellite transmission of ocean colour imageries. Monthly hits were high (200-300) in February, April, November and December (Fig. 2).

The spread of the PFZs as indicated by the lines in the chart showed wide variation (Fig. 2). During November to March, the PFZs covered on an average of 11 to 14 zones in the chart and from April to August

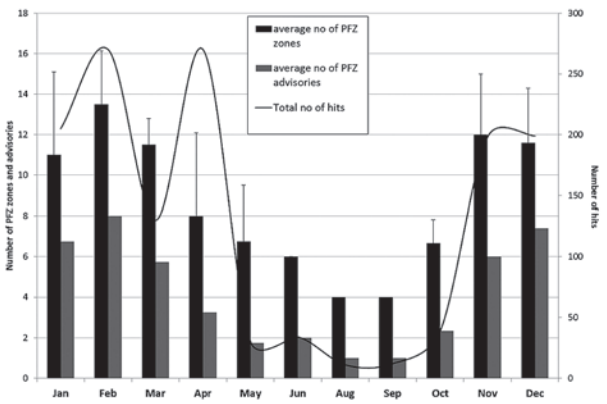

Fig.2–Average number of PFZ advisories, average number of zones covered ('Spread') and average number of hits per month during the period 2003 to 2007. Vertical line indicates standard deviation. No advisories are available for July.

there was a decline in the spread (4 to 8 zones). This can be either due to the less number of advisories or due to the low productivity of the area during monsoon. Studies on spatio-temporal variability of productivity in the Arabian Sea have clearly indicated that during the spring inter-monsoon period (March to May) the entire Arabian Sea has very low productivity (14 to 21 m mol C m^2 d^{-1}) and cholorophyll (ca 45 m mol C m^2) and the entire Arabian Sea attains the Typical Tropical Structure[17] with higher SST, shallow mixed layer depths and strong stratification and a similar situation prevails during Sepetember-October also[18].

The NS region with 2682 (58%) hits was the area where PFZs formed frequently followed by MS (n=994) and CS (n=956) with 21% in each. Zone 4 (Lat 11° to 12°N; Long 75° to 75°50'E), the coastal area between Beypore and Kannur was the most productive with 893 hits followed by Zone 9 (off Kochi-Alleppey) with 802 hits (Table 1; Figs. 3, 4 and 5). Zone 2 (off Kasargod) and Zone 6 (off Ponnani) were medium ranked with 752 and 523 hits respectively. Minimum (n=1) was observed in Zone 14 (Lat 7° to 8°N; Long74° to 75°E) which was in the CS area off south Kerala. Moreover, zones in the CS region like Zone 10 and Zones 15 to 17 also ranked low with less than 50 hits.

Earlier studies[19] have indicated that in the region off Calicut (Lat 11° to 12°N), the intrusion of offshore cold sub-surface waters into the shelf is conspicuous in the form of a tongue and the top of the thermocline touches the very surface areas in the inshore region and an eastward gradient of temperature is observed in the surface layers. Such features can result in increased productivity. More recently, there are reports[20] of cooler waters along the coastline and a strong thermal front between 73°-75°N longitudes, with a thermal gradient of 0.02°C. km^{-1}. Salinity and density based fronts were also seen in this region.

The NS zones are more influenced by river discharges compared to the MS and CS areas. In Kerala, there are 41 west flowing rivers and this would have led to the formation of more SOPs in the NS

area compared to the outer regions. In NS area of Zone 4 between Beypore and Kannur, there are nearly 8 rivers which discharge annually about 14,507 Mm^3 water into the sea (Table 2). Simliarly, the Vembanad Lake, the largest lake and backwater system in Kerala is spread along Kochi and Alleppey making this region also more productive. In the southern part, apart from the Ashtamudi Lake in Kollam, there are no major rivers flowing into the Arabian Sea and this could have led to the low ranking of southern zones. Compared to the region off Thiruvananthapuram, the coastal waters off Kollam have more hits. The observation of relatively low salinity off Kollam than Thiruvananthapuram indicated the role of runoffs (Kallada River) in creating a upper stratified layer (warm and low saline) especially in the upper 15m depth region[21].

In the NS region 4K (Lat 11°15' to 11°30'; Long 75°30' to 75°45'; between Calicut and Kadalur), 4A (Lat 11°45' to 12°00'; Long 75°00' to 75°15'; off Kannur) and 9A (Lat 9°45' to 10°00'; Long 76°00' to 76°15'; off Kochi) were the most frequently occuring grids with more than 125 hits each (Fig. 3). When all the grids irrespective of regions are considered, again these three grids were the most frequent. One common feature of these three grids is that all the three depth contours namely 10, 20 and 30 m pass through these grids. Moreover, in the northern grids, rivers like Korapuzha, Kuttiyadi,

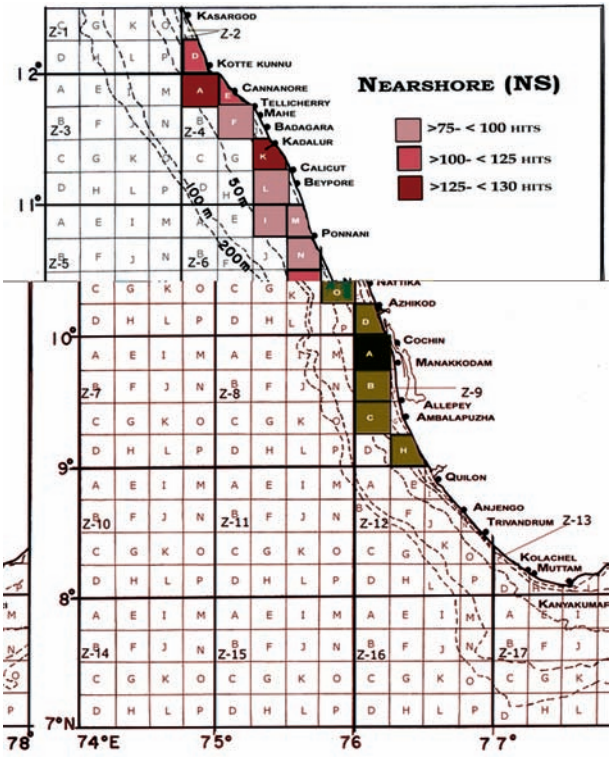

Fig.3–Map showing top-three frequencies of PFZ hits in grids in near shore (NS) region in the Arabian Sea off Kerala. Legend shows frequency gradations with higher frequencies in dark colour.

Kallayi, Kavvayi, Kuppam and Valapattam flow to the Arabian Sea in these areas. In the region off Kochi, real time obsevations[22] have indicated that during the wet months, discharge from the Vembanad Lake, characterized by suspended sediments, spreads

Table 2–Details of the number of PFZ hits in different latitudes

Latitude°N	Longitude°E	Zones covered during 2003 to 2007	No of PFZ hits	%total hits	Average annual river discharge (Mm^3)
12 to 13	74 to 75 15	1, 2	886	19	8269
11 to 12	74 to 75 50	3, 4	1138	25	15644
10 to 11	74 to 75 15	5,6,6'	1110	24	10222
9 to 10	74 to 76 30	7,8, 9	859	19	15953
8 to 9	74 to 76 30	10,11,12,13	585	12	6230
7 to 8	74 to 78	14,15,16, 17	54	1	0
Total			4632	100	56318

Mm^3 – Million cubic meters

as a plume, over highly saline and cold upwelled water, turning the region into an intermittent estuary. Though the end of the plume can often be pinpointed around the 30 m depthline, by a sharp change of colour and filaments formed of floating objects of land and freshwater origin, the presence of an actual plume front was considered doubtful because of the weak surface convergence. These observations are indicative of more frequent SOPs occuring in grids 4K, 4A and 9A. The region off Kochi-Alleppey is also known for the formation of "mud banks" which has unique features and these regions also support good fisheries[23].

In the NS region all the grids have PFZs throughout the study period. Other grids of Zone 4 such as 4L and 4F, and 6N, 6M and 6I of Zone 6 were also persistent with number of hits ranging between 100 and 125. Thus, in general, it can be stated that the NS region between Ponani and Kottakunnu frequently occurs as PFZs. Several freshwater sources like Bharathapuzha, Karuvannur and Keecheri empty into the Arabian Sea in areas near to Zone 6 thereby making the nearby areas more prone to density differences.

In the MS area, grids 4H (Lat 11°00' to 11°15') and 6E (Lat 10°45' to 11°00') lying between the same Long 75°30' to 75°45' (between Ponnani and Calicut) were the most frequent (Fig. 4). Grid 1K (Lat 12°15' to 12°30'; Long 74°45' to 75°00'; off Kasargod) and 9D (Lat 09°00' to 09°15'; Long 76°00' to 76°15') lying south of Ambalapuzha and north of Kollam were moderately ranked with more than 40 hits. Higher concentration of nutrients have been observed in the open part of the Arabian Sea at or near the base of the photic zone, especially at regions of upwelling with high production rate being recorded in the euphotic zone[24]. Similarly, correlation of oceanographic features with zooplankton biomass and abundance of fish eggs and larvae shows that the continental shelf region along the southwest coast is markedly richer than the offshore regions as far as plankton biomass is concerned.

In the CS grids 6A, 6B, 6C, 6G,6H and 6L lying in the region north off Kochi and south off Beypore

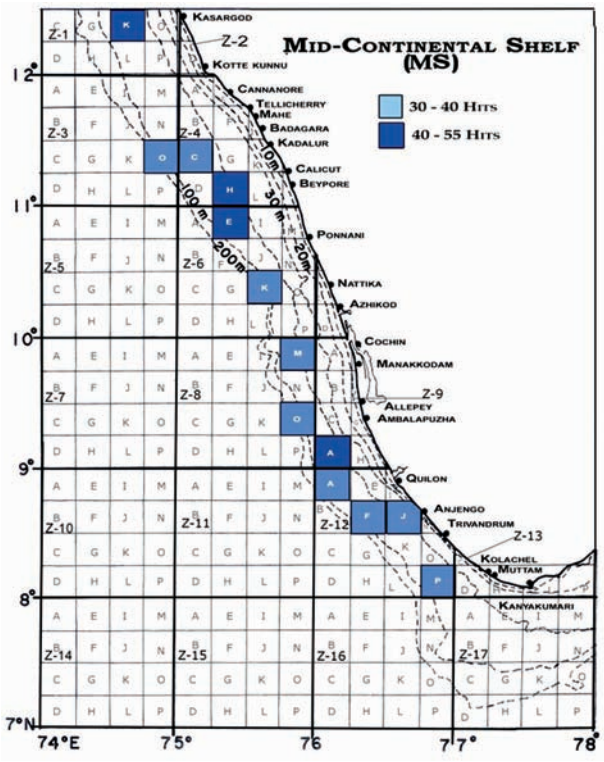

Fig.4–Map showing top-two frequencies of PFZ hits in grids in mid-continental shelf (MS) region in the Arabian Sea off Kerala. Legend shows frequency gradations with higher frequencies in dark colour.

were most frequent (Fig. 5). Grid 1H (off Kottekunnu) 8J (between Manakkudam and Alleppey) and 11G (off Thiruvananthapuram) were ranked next in order. The number of hits in these grids were in general low, with an average of 23 hits. Of these 9 grids, 5 were partly in the 100-200 m depth contour and the rest were outside the 200 m depth contour. PFZs rarely occurred in the grids away from the 200 m depth contour. In a description of biomes of Western India Coastal Province, Longhurst[25] reported that shelf-break front upwelling is not very frequent in this region, although the reasons are not clear.

High larval abundance has been observed near the coast in the northwest Mediterranean in zones with topographic irregularities that can greatly modify circulation favouring penetration of slope waters into the shelf[26]. In the same study high larval concentrations have been observed over the edge of the continental shelf in relation to the presence of the shelf-slope front and its associated convergence. In

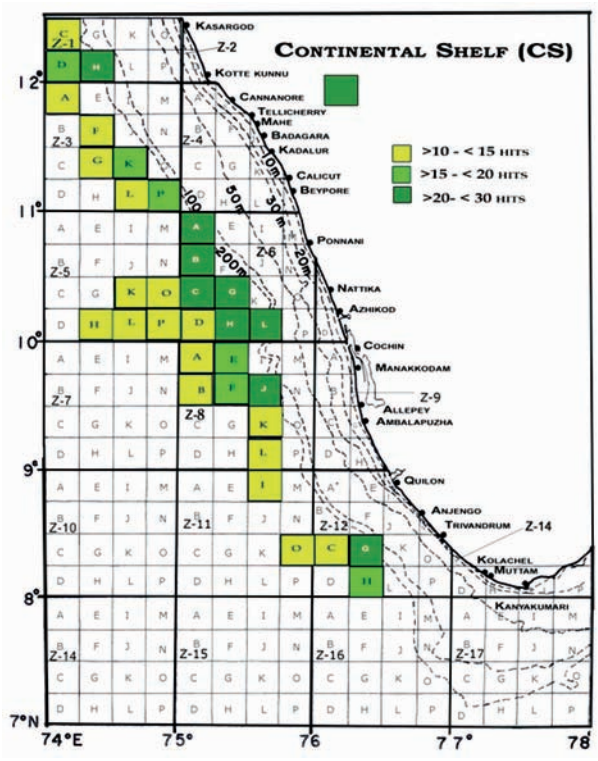

Fig.5–Map showing top-three frequencies of PFZ hits in grids in continental slope (CS) region in the Arabian Sea off Kerala. Legend shows frequency gradations with higher frequencies in dark colour.

the open ocean also fronts occcur[25], and the "siomes"of Japanese fishermen are areas where turbulence at the confluence disburbs the wind-wave systems and aggregation of biota concentrate pelagic fish and birds and attract fishers[27].

The study area covered 6 latitudes (7 to 13°N), and among these, latitude 11° to 12°N (Calicut to Kannur) had the highest number of hits (n=1138; 25%) followed by the region between 10° to 11°N (north off Kochi to South off Beypore) (N=1110; 24%) (Table 2). Less frequent were the regions between 12° to 13°N (off Kasargod) and 9° to 10°N(Kochi to Kollam) with 19% of the hits in each region. The region between lat 8° and 9°N had only 13% of the hits while that between 7° to 8°N had only 1% of the total hits. Productive regions like fronts can originate from mixing of waters with varied temperatures, densities and salinities and these can give rise to areas with high productivity. Increased productivity can also be due to nutrient rich river runoff from the land especially the nearshore regions of north and central Kerala.

Average annual river discharge (Table 2) was highest, 15,953 Mm^3 in the 9° to10°N where 859 hits were recorded followed by the 11° to12°N region. Pearson correlation analysis indicated significant relationship ($R=0.847$; $P<0.05$) between the number of hits and the average annual river flow into the sea.

Oceanographic studies in this region[14,18,28] also indicated the significance of salinity in SOPs in areas with depths less than 50 m. There are reports of a surface, weak, northward drift between 11° and 13°N, which deflects northwestwards around 13°N, and attains good velocity[28]. A similar pattern of circulation was found at 10, 20, 30 and 50 m depths. Such discrepancies disappeared further below at 75 and 100 m depths, where the temperature discontinuity layer usually started. It was inferred that the thermal fields present comparable type of circulation only below a depth of 75 m, and the discrepancy in the upper layers (0-50 m) was inferred as due to the effect of salinity. Salinity variations are mainly due to rainfall and river runoff. Hence, it can be inferred that the river runoffs plays a critical role in developing PFZs. In the southern part of Kerala there are few rivers and this could be a reason for low number of PFZ hits in this area. The relationship between the amount of water discharged onto the continental shelves and the fish production has been investigated globally and it was observed that in general, a positive correlation exists between mean annual river discharges and the catch rate of neritic fish in the adjacent shelf[29].

Another distinct feature in coastal habitats is the occurrence of large extent of mangroves[30] in the 11° to 12°N latitude. Almost 69% of the mangoves in Kerala occur in the district of Kannur. The high organic productivity of the magrove habitat will be reflected in the river runoff from this region and would have contributed to the persistent occurrence of PFZs in this region. The role of nutrients in enhancing the productivity and complexity of nutrient dynamics in controlling the coastal and shelf

productivity is largely understood[29] and it can be assumed that in the present study area also nutrients from the nearshore regions have contributed to productive SOPs in the southeastern Arabian Sea.

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