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Evaluation of remote-sensing-based potential fishing zones (PFZs) forecast methodology

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Abstract

Satellite-based potential fishing zones (PFZs) forecasts were generated using integration of Ocean Colour Monitor (OCM) derived chlorophyll concentration and Advanced Very High Resolution Radiometer (AVHRR) derived sea surface temperatures (SST). Validation of the PFZ forecasts was carried out during seasons 1999–2000, 2000–2001 and 2001–2002 using Fishery Survey of India vessels. Bottom trawl catches were composed of mixed species from different habitats, i.e. demersal and pelagic. Hence, there is a need to understand the application of satellite-derived PFZs to different species types of fishery resources. The per cent contribution by species was determined from 30 m to 100 m depth range. Those species contributing 5 kg/haul and above were considered as a significant species. Species-wise catch per unit effort (CPUE), seasonal mean CPUE and standard deviation (SD) were computed for remotely sensed PFZs and the entire region. Species-wise comparisons were made between mean CPUE in PFZs and seasonal mean CPUE in other areas from a different habitat. It was observed that fishery resource of pelagic and water column habitats contributed fairly well as compared to the demersal resources in PFZs. The per cent contribution of pelagic and water column species were found more in PFZs catch as compared to the seasonal mean catch in other areas. In this study, diet composition and feeding habitat of fishes and its relationship to satellite-derived parameters have been evaluated.

Keywords: Fish; PFZs; Chlorophyll concentration; SST; Remote-sensing

1. Introduction

Fishery resources surveys using actual sampling and data collection methods require extensive ship time and sampling time. Remote-sensing, combined with conventional data collection techniques, provides a powerful tool for designing harvesting strategies for living marine resources. Satellite remote-sensing provides synoptic views of the ocean and is capable of detecting mesoscale features through thermal infrared and visible sensors; hence, it can be useful for locating potential fishing zones (PFZs). The use of satellite capabilities in fisheries research has been studied by Lasker et al. (1981), Laurs et al. (1984), Fiedler et al. (1984) and others. Water masses classified by satellite-derived sea surface temperature (SST) and ocean colour images have been associated with different biological and physical processes (Arnone, 1987). Indian

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remote-sensing satellite-modular opto-electronic scanner (IRS-MOS) and NOAA AVHRR data have been used to characterise the relationship between the physical and biological variables in coastal waters and it was observed that the chlorophyll concentration and SST were inversely correlated (Solanki et al., 1998). Synergistic analysis of satellite-derived chlorophyll and SST features were carried out by Solanki et al. (2001b) who observed that chlorophyll and SST features coincided at some locations indicating close coupling between biological and physical parameters. An integrated approach was developed by Solanki et al. (2000, 2001b) using ocean colour monitor (OCM) derived chlorophyll and AVHRR derived SST for locating PFZs in the Indian waters. PFZs validation experiments were carried out during October 1999 to March 2002 through actual fishing by Solanki et al. (2001a, 2003). Validation of results indicated an average increase in the catch weight by 200% in pelagic resources caught by gillnets (Solanki et al., 2001a). The analysis of trawling data indicated a 70% success rate and increase in catch by weight of about 80% in PFZs areas as compared to other areas (Solanki et al., 2003). Trawl catches were composed of ribbon fishes, mackerel, cat fishes, squids, barracuda, sciaenids, etc. The objectives of the present study were (i) to evaluate remotely sensed PFZs forecast methodology for different types of fishery species, (ii) to understand why this integrated approach works better for pelagic than for demersal resources, and (iii) to relate remotely sensed variables with the composition of the fishery species and their diet and feeding habitat in PFZs.

2. Study area

The study area was the highly productive region, off the Gujarat Coast in the northern Arabian Sea that comprises extensive fishing grounds (Fig. 1).

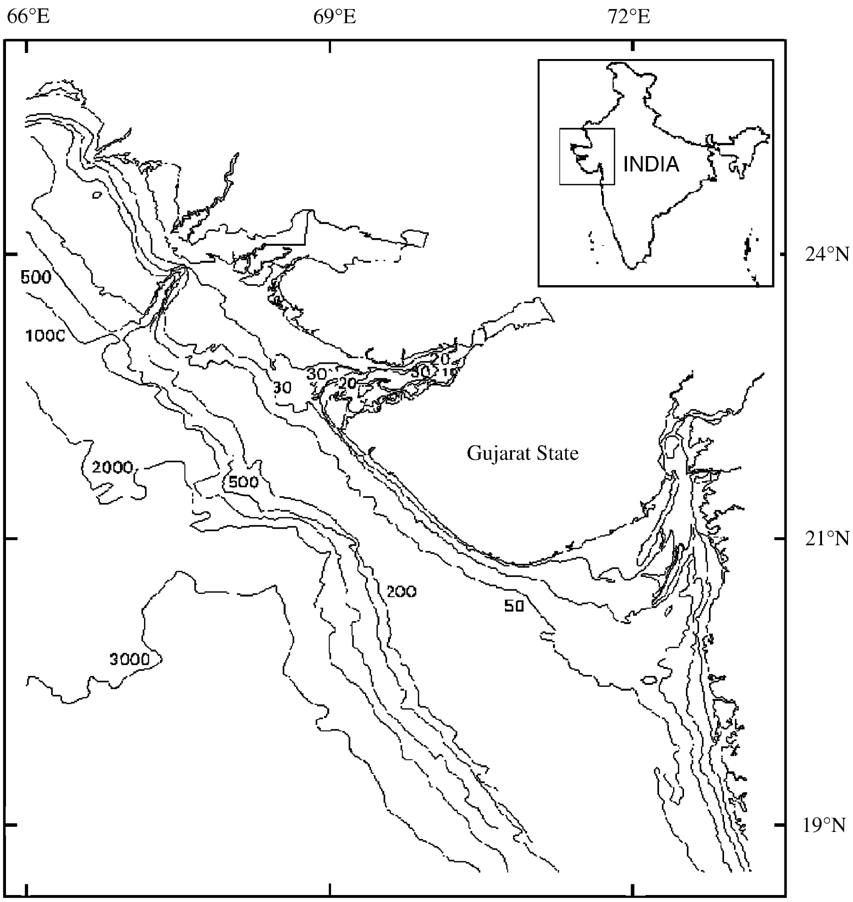

Fig. 1. Location map and bathymetry of the study area, off Gujarat coast (India), in the northern Arabian Sea. Depth contours are in meters.

Gujarat State has the longest coastline of 1640 km among the maritime States of India. The continental shelf area along the State (Latitude 20°N–23°N) is about 90,200 km^2, is the largest shelf area among the Indian maritime states and has a maximum continental shelf width of about 305 km. The gradient of the shelf is 1:1769 at the maximum width and 1:537 at the minimum width. The powerful cyclonic Somalia current grazes the Saurashtra coast during the southwest monsoon. During the northeast monsoon, offshore winds along the Kathiawar peninsula induce the primary production and high fish production. The total biomass in the continental shelf along Gujarat coast was estimated to be 4.4 lakh metric tonnes (Bhargava et al., 1995). About 67% of this were in water up to 50 m in depth, 26% in the 50–100 m depth range and 6.5% in the 100–200 m depth range.

3. Data used

OCM data for chlorophyll concentration and AVHRR data for SST computation was used. Table 1 shows the detailed characteristics of OCM and AVHRR payloads. PFZs catch data collected by the survey vessels (*Matsya Nireekshani* and *Matsya Mohini*) of the Fishery Survey of India (FSI) during the validation experiment phase II (2000–2001) and phase III (2001–2002) were utilised for the present study. The sampling thus conducted pertained to the depth zone 30–100 m.

4. Methodology

4.1. Satellite data processing

4.1.1. IRS P4 OCM data processing

The retrieval of phytoplankton pigment (i.e. chlorophyll a) in seawater involves two major steps. The first is known as the atmospheric correction of visible channels to obtain normalised water leaving radiance and the second is the application of bio-optical algorithm for chlorophyll concentration retrieval. In oceanic remote-sensing the radiance backscattered from the sea surface is typically larger than the desired water leaving radiance L_w. The process of retrieving L_w from the total radiance measured at the sensor L_t is usually referred as the atmospheric correction. In the case of oceanic remote-sensing, the total signal received at the satellite altitude is dominated by the radiance contribution through atmospheric scattering processes and only 8–10% of the signal corresponds to oceanic reflectance. Therefore, it has become mandatory to correct for atmospheric effects in order to retrieve any quantitative parameter from space. Atmospheric correction of OCM channels was carried out using the approach suggested by Gordon and Clark (1980).

Chlorophyll concentration was estimated from the retrieved spectral water leaving radiance by the application of bio-optical algorithms. An empirical Ocean Chlorophyll 2 (OC2) algorithm suggested by O'Reilly et al. (1998) was used with modified coefficients (Chauhan et al., 2002) for retrieval of

Table 1
Technical characteristics of OCM and NOAA AVHRR payload

Parameter	OCM	NOAA AVHRR
Swath (km)	1420	2700
Equatorial crossing time	12 noon	0230 & 1430 h
Spectral range	402–885 nm	0.58–12.5 μm
Quantisation (bits)	12	10
No. of channels	8	5
Spatial resolution	360 m	1.1 km
Wavelengths	Channel 1—402–422 nm Channel 2—433–453 nm Channel 3—480–500 nm Channel 4—500–520 nm Channel 5—545–565 nm Channel 6—660–680 nm Channel 7—745–785 nm Channel 8—845–885 nm	Channel 1—0.58–0.68 μm Channel 2—0.72–1.1 μm Channel 3—3.55–3.93 μm Channel 4—10.3–11.3 μm Channel 5—11.5–12.5 μm
Repetitive	2 days	Daily

chlorophyll concentration. This algorithm operates with five coefficients:

$$C = 10^{(0.319-2.336R+0.879R^2-0.135R^3)} - 0.071, \quad (1)$$

where C is the chlorophyll concentration (mg/m^3) and $R = \log_{10}[R_{rs}\ (490)/R_{rs}\ (555)]$, where R_{rs} is remote-sensing reflectance.

4.1.2. NOAA AVHRR data processing

The brightness temperature sensed at satellite height is influenced mainly by atmospheric moisture. The signal loss due to water vapour absorption is proportional to the radiance difference in the measurement made at two different channels of the thermal infrared. The MCSST approach suggested by McClain (1985) was used to compute SST from AVHRR thermal infrared channels, i.e. Ch no. 4 (10.3–11.3 μm) and Ch no. 5 (11.5–12.5 μm). Preliminary geometric correction was carried out according to an approach suggested by Narayana et al. (1995). This approach uses the satellite ephemeris. The precise geometric corrections were carried out using a set of ground control points (GCPs) located both on an image and a Naval Hydrographic Office (NHO) bathymetric map. This geo-reference master image was used for image-to-image registration of AVHRR channels in order to generate a geo-reference data set. Colour-coded SST images were generated which indicate the distribution of SST in the northwest Arabian Sea. The same

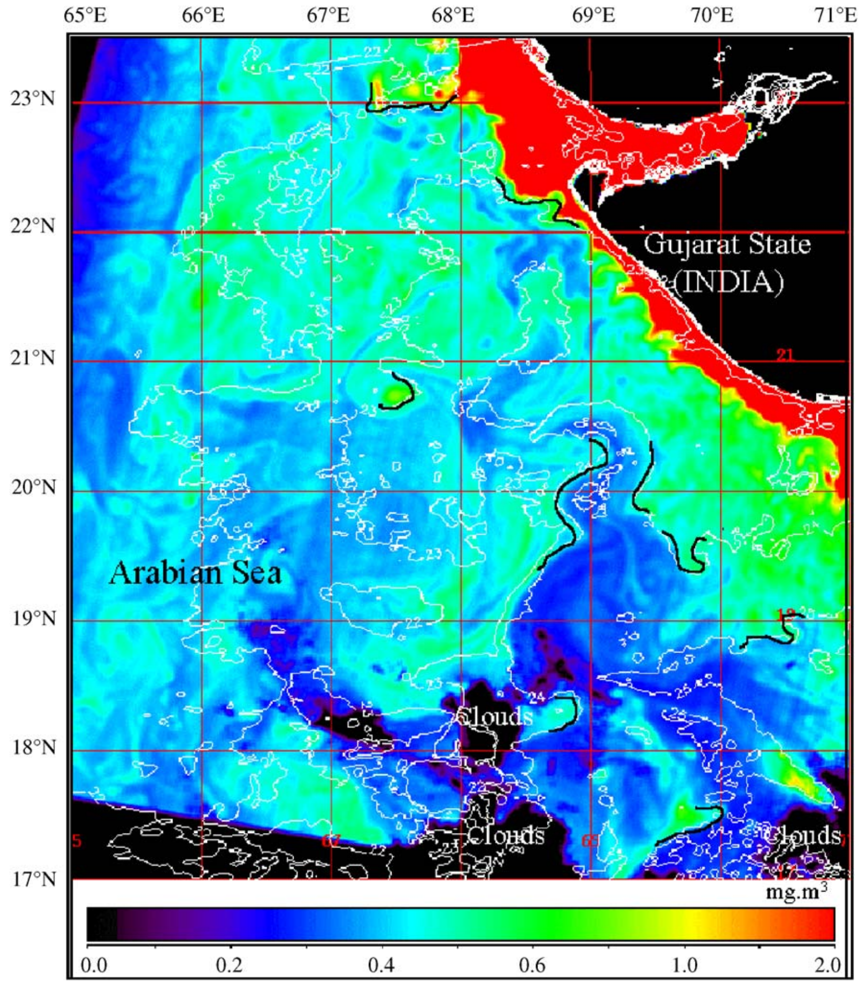

Fig. 2. Typical composite image generated from satellite-derived chlorophyll concentration image (background image) and sea surface temperature (SST in °C) contours. Synchronous near-real-time satellite data of 8 March 2000 was used. The image shows matching features of chlorophyll and SST. Black lines in the images indicate the suggested PFZs.

colour scheme was applied to both chlorophyll and SST images to make easy comparison between the two variables.

4.1.3. Generation of chlorophyll and SST composite

Geometric registration of imagery was important for the comparison between the two different sensor data types. To co-register these two data types, a master image was generated using GCPs located on an image as well as on a map. This was followed by map–image registration. Output master images were used to co-register chlorophyll and SST images in order to generate geo-coded images. In order to visualise both parameters in the single product, a chlorophyll and SST composite product was generated. For this, SST images were filtered to remove the noise using a low-pass filter. These filtered images were used to generate contours showing different SST. The contours were converted into vectors. These vectors were overlaid on chlorophyll images to generate a chlorophyll–SST composite showing chlorophyll and SST features/values (Fig. 2).

4.2. Fishery forecast and validation experiment

The common features observed in both images were identified and monitored in the composite image. For this, past images were used to know the appearance and persistence of oceanographic features such as eddies, rings, fronts with large gradients, meanders, etc. The latitude and longitude of these features were recorded from the composite image. Water depths at these locations were recorded from the co-registered digitised hydrographic maps. The remotely sensed oceanic features along with suggested tracks were communicated to fishing vessels within 24 h. Two dedicated fishing vessels namely; *Matsya Mohini* and *Matsya Neerikshani* were kept ready for fishing. The vessels immediately proceeded to the given coordinates to fish within the identified features. Four daily trawl net samples were taken in the suggested areas. The details of fishing and catch were entered in the log sheets of FSI. These log sheets were used for fishing data.

4.3. Analysis of fishing operations

The actual fishing data in PFZs and other areas were procured from FSI. The abundance index of species contributing 5 kg and above was considered as key species in trawling. A statistical analysis of total catch in PFZs and other areas was carried out (Table 2). Species-wise catch per unit efforts (CPUEs) for each sample were calculated to normalise the fish catch. These species-wise CPUEs were used to compute mean CPUEs and standard deviation (SD). Key species caught in the trawl catch and their per cent contribution were calculated. Table 3 represents comparison of per cent contribution in other areas and in PFZs of each species. Species-wise seasonal mean CPUE for the entire fishing area was computed and compared with mean CPUE in the PFZs (Fig. 3).

Table 2
Results of statistical analysis of total catch composed of all dominating species during validation

Sl. no.	Particulars	Seasonal CPUE	PFZs CPUE
1	Mean	121.085	177.35
2	Observations	81	81
3	SD	36.05	136.26
4	SE	4.08	15.43
5	95% confidence interval	121.085 ± 8.13	177.35 ± 30.72

5. Results and discussion

5.1. Remotely sensed PFZs

Satellite-derived chlorophyll concentration provides a measure of the areas of enhanced biological production. Remotely sensed SST characterises the oceanic environment suitable for enhanced biological production. The zooplankton and fish population are known to accumulate for feeding and spawning at oceanic features like fronts, eddies, rings, meanders and upwelling. The use of both variables would explain the oceanic environment and food resource availability in an ecosystem for exploring fishery resources.

A typical output generated using integration of the chlorophyll concentration and SST image is shown in Fig. 2. SST contours overlaid on the chlorophyll concentration image indicate some matching features in images derived from both optical and thermal infrared sensors. Cool water is an indicator of high nutrient waters. In such areas, the probability of enhanced production is greater than for stratified warm waters. This indicates that there is an inverse relationship between chlorophyll

Table 3
Statistical analysis and per cent contribution of dominant species of different habitat in PFZs and other areas for 81 observations

Species	Habitat	Seasonal (in other areas)			PFZs			% seasonal contribution	% contribution in PFZS	% increase in PFZs
		Mean CPUE kg h^2	Standard deviation (SD)	2 Standard error of mean	Mean CPUE kg h^2	Standard deviation (SD)	2 Standard error of mean			
Ribbon fish*	Pelagic	31.07	19.2	±4.26	61.17	10.2	±2.26	11	15	96.87
Catfish*	Demersal	52.69	14.1	±3.1	150.37	17.5	±3.88	19	35	189.18
Horse* mackerel	Pelagic	7.16	2.0	±0.44	31.60	8.4	±1.86	3	8	332.90
Mackerel	Pelagic	15.80	5.4	±1.2	20.25	3.2	±0.71	6	5	26.50
Lesser sardine	Pelagic	12.30	4.0	±0.88	13.66	3.8	±0.84	4	3	11.60
Squids	Column/ pelagic	8.80	3.0	±0.66	10.80	2.1	±0.46	3	3	22.00
Barracuda	Pelagic	14.34	6.0	±1.33	11.01	2.2	±0.48	5	3	−23.29
Nemipterids*	Demersal	31.66	10.4	±2.31	17.18	6.8	±1.51	11	4	−45.70
Decapterids	Columner	62.22	10.6	±2.35	80.00	9.8	±2.17	23	19	28.57
Dhoma	Demersal	40.70	9.4	±2.09	20.90	4.4	±0.7	15	5	−48.60

*Significantly difference comparing the PFZs and seasonal observations (sample size) = 81.
Source: Fishery Survey of India, Mumbai.

concentration and SST (Solanki et al., 1998a). Areas of matching features were selected as PFZs and suggested for experimental fishing (Fig. 2). The coincidence of chlorophyll and SST features at some locations indicates that physical and biochemical processes are closely coupled at these locations. High catch points were observed in the vicinity of thermal as well as colour persistent features (Laurs et al., 1984; Solanki et al., 2001b). Thus coincidence of ocean colour and thermal features can be utilised for exploring fishery resources. The selection of features and their relevance to fishery resource distributions have been discussed by Solanki et al. (2003).

5.2. *Per cent contribution of species*

Fig. 3 depicts the comparison of species-wise seasonal mean catch with the mean catch in PFZs for the season October 2000–March 2001. Significant increase in the catch of ribbon fish, catfish and horse mackerel was observed in the PFZs as compared to seasonal mean catch. The ribbon fish and mackerels are pelagic. Comparatively low catches of sciaenids, decapterids and nemipterids were observed in the PFZs as compared to seasonal mean catch from the entire fishing area. These are the demersal group of species. Other species showed marginal increase in the PFZs. Cat fishes being demersal in habitat contributed a fairly high catch in the PFZs as compared to their seasonal mean. The catfishes inhabit the muddy bottom. The nutrient supply on a muddy bottom is known to continue for a longer period and favours phytoplankton growth in the areas, which can be captured/sensed by ocean colour sensor.

The paired *t*-test was carried out for these observations. The values for *t*-stat, *t*-critical (one tail), and *t*-critical (two tail) were 4.1757, 1.66, 1.66, respectively. The results of *t*-test indicated that *t*-stat > *t*-critical for both one tail and two tail, which is statistically significant. A 95% confidence interval for the total catch composed of all dominating species has been indicated in Table 2.

Table 3 shows the comparison of detailed statistical analysis and per cent contribution of dominating species by weight in the entire area (seasonal) fished within the PFZs by trawl during validation. The table indicates the mean CPUE, standard deviation, standard error and per cent contribution of different species in PFZs and other areas for 81 observations. It may be seen that about

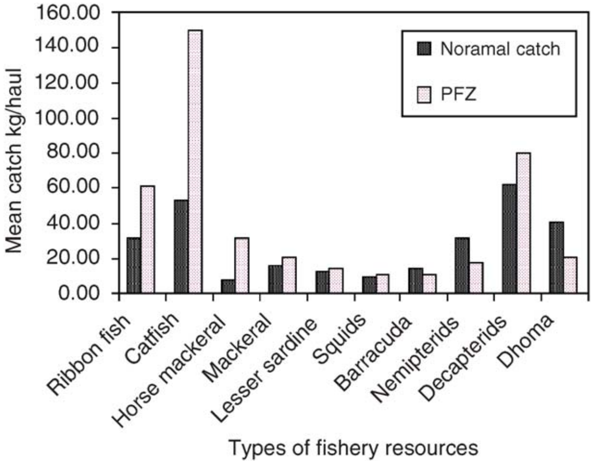

Fig. 3. Comparison of fishery resources composition between seasonal mean CPUE (normal catch) in other areas and mean CPUE in remotely sensed PFZs. The fishery resources are from different habitats.

50% of the catch were composed of ribbon fish and cat fish in the PFZs, while the seasonal contribution by these species together was 30%. The contribution of the demersal species like sciaenids was 5% in PFZs as compared to 15% seasonal contribution of these species. The per cent contribution of Nemipterids was only 4% in PFZs while their seasonal per cent contribution was 11%. However, rest of the species were observed to be marginally increased or decreased in the catches from the PFZs. This clearly indicates that basically, the technique is more suitable for pelagic resources as compared to the demersal resources. However, the catch of cat fishes is highly significant and, being demersal in habitat then per cent contribution in trawl catch from the PFZs is 35% as compared to the seasonal mean contribution of 19%. This may be because of their bottom habitat where the muddy bottom supports a high nutrient supply enriching the ecosystem. These results call for improvement in the technique through incorporation of other relevant parameters like bottom nature, wind speed, sediment concentration, bathymetry, current, etc., and interpretation of the results in a GIS environment.

The per cent contribution of pelagic and water column resources are more in the PFZs as compared to seasonal mean of the entire area during the fishing season. Comparatively, the contribution of the demersal resources in the catches is lower in PFZs. The limitation of satellite sensors to visualise the marine resources at the bottom is apparent, as the catfish catches were found to be higher on the muddy bottom. The exploration of demersal resources through remote-sensing is based on the linkages between the surface/water column production of biomass with distribution of detritus material and living resources at the sea floor. This can further be linked with the vertical migration of biomass and movement of the demersal resources towards the upper layers of the water column in search of food, causing variation in the local ecosystem at different trophic levels, which supports benthic biomass. The contribution of pelagic and midwater fishery resources in the bottom fishing may be due to the bottom depth (30–100 m), that happens to be within the light penetration depth. Hence, the entire water column is suitable for plankton production. This enables the pelagic/water column resources to traverse and dwell on the bottom.

5.3. Habitat of fishery resources and link with satellite-derived in PFZs

A vast historical database of published studies exists (Froes and Pauly, 2000; Bal and Rao, 1990) which has enabled a number of useful generalisations to be made for ecosystem-based management of fisheries. The food and feeding habitats of commercially important species that significantly contributed to fish, to the catches in PFZs has been compiled in Table 4. The information on food and feeding habits of fishes is essential for a better understanding of their life history including growth, breeding and migration. This information is also important for management of fishery resources using remote-sensing. The knowledge of favorable feeding grounds of commercial fish stocks is of great practical significance to fishermen to expand their fishing effort profitably. Partially, this information can be derived through the interpretation of remotely sensed parameters. At the same time, knowledge of prey–predator relationship is very useful to interpret availability and management of fishery resources using remotely sensed techniques.

Fishing operation results indicated the mixed fish catch of species belong to different habitats, i.e. pelagic, demersal and water column habitat. The sampling efforts in term of actual fishing were carried out in 30–100 m depth of the continental shelf. In this area the majority of the water column comes well within light penetration depth. This enables distribution of pelagic and water column species down to the bottom. Hence, the fishery

Table 4
Description of food and feeding habits of significantly contributed fishery resources in PFZs

Sl. no.	Common/English name	Species name	Habitat	Food and feeding habitat
1	Ribbon fish	*Trichiurus lepturus*, *Lepturacanthus savala, Epleurogrammus intermedius*, and *E. muticus*	Pelagic	The food of ribbon fish consist of fish followed by crustaceans, shrimps including, acetes, squilla. The diet of adult consist of fishes like *Stelephorus, Thrissous, Sphyaena, Hemirhamphus, Sardinella, Tetrodon, Leiognathus, Dussumieria, Atherina, Stolephorus, Sardenella, Kowala coval, Ploynemids*. Rest of the diet is made up of acetes, other shrimps, squilla, crab larvae, megalopa larvae, young ones of Sepia, zoea larvae. Lucifer, alima larvae of stomatopods, etc. The food items preferred show that the fish is surface feeder. Ribbon fish are predacious, carnivorous and some times cannibalistic feeders. Majorities are pelagic feeders.
2	Cat fish	*Tachysurus sona*, *T. maculates*, *T. thalasinus*, *T. dussumieri* and *T. jeilla*	Demersal	*T. sona* feeds mostly on fish and crustaceans. The fish diet consists of eel larvae, young ones of *Harpodon, Trichiurus, Coilia, Anchoviella, Chirocentrus*, etc. Crabs, shrimps, squilla, mollusks, acetes and salps form the next important item. *T. maculates* feed on detritus and polychaetes particles. Other items like foraminifera, ocstracods, amphipods, shrimps, squilla, crabs, bivalves consumed throughout the year, and the food items always found in association with mud and sand suggesting that they are benthic feeders. *T. thlassinus* and *T. tenuispinis* are the voracious carnivores feeds at bottom mainly on crustaceans like crabs, prawns, squilla, teleosts and mollusks. *T. dussumieri*, a predacious carnivore consumes bivalves, gastropods, crabs, acetes, ploychaetes, whereas *T. jella* favours cephalopods and crabs. Cat fishes are generally predatory, carnivorous and scavengers, and voracious bottom feeders. They generally prefer muddy ground for distribution.
3	Sciaenids (dhoma, ghol, croakers, jew fish, koth)	*Pseudosciaena diacanthus* (ghol) and *Otolithoides brunneus* (koth), *Otolithes ruber, O. argenteus, Johnius dussumeri* (dhoma)	Midwater	Their feeding preferences are generally crustaceans, followed by fishes and a certain extent on mollusks, echinoderms, annelids. *P. diacanthus*-favoured forms are *Ilisha filigera, Thrissaocles, Nemipterus japonicus, Caranx, Leiognathus*. Their crustacean food consists of *M. affinis, P. tennuipes*, along with crabs, bivalves, gastropods and cephalopods are also consumed.
			Midwater	*Otolithoides brunneus* also switches its preference from crustaceans in its juvenile stage to piscivorous consist of *Coilia dussumieiri*, *Trichiurus* and *H. nehereus*.
			Demersal	*Otolithus ruber* prefers cruacean food, throughout the year, fish form the secondary food item, while cephalopods are taken occasionally. The fish food consists of *Bregmaceros* sp., *P. heptadactylus*, *Sciaena* sp., *Stromateus* sp., *H. nehereus*, etc. *O. argenteus* feeds occasionally on *echiuroids, polychaetes* and *mysids*, in addition to its main items of food, viz. crustaceans and

				fish. Among the *crustaceans, Acetes* and *Squilla* are the main species favored, and fish like *Stolephorus, Bregmacerous.* In general, ghol and koth are carnivorous and active predators. They are surface and midwater feeders. Domas are bottom feeder but *O. rubber* seems to restrict itself to surface and midwater feeding. *O. argenteus* like *O. rubber* is a surface feeder.
4	Barracudas	*S. jello* and *S. commersonii*	Pelagic	The food composed of fish like *Bregmaceros mcclellandi*, *Appogon* spp., and crustaceans throughout the year. They are pelagic, diurnal and solitary but can be found in small schools. They are predaceous and carnivorous.
5	The lesser sardines	*Sardinella jussieu, S. albella, S. fimbriata, Kowala covla, Dussumieri acuta, D. seltii*	Pelagic	They are essentially plankton feeders with preference for zooplanktonic organisms, diatoms, filamentous algae. *Sardinella jussieu,* and *S. albella* feed on zoea larvae, copepods, lucifer, pteropods and blue green algae *Trichodesmium erythraeum. S. fimbriata* feeds on phytoplankton and zooplanktonic organisms. *Kowala covla* is a plankton feeder, with zooplanktoinc organisms dominating among its food. *Dussumieri acuta* feeds on crustaceans while *D. hasseltii* are known to subsist on planktonic organisms. Majority of them are plankton feeders.
6	Squids	*Sepioteuthis arctipinnis* and *Lologo duvauceli*	Pelagic	Cruastaceans, viz. shrimps and crabs and small fish constitute the principal food. They are also cannibalistic in its diets. They are pelagic and move in shoals.
7	Mackerel	*R. kanagurta, R. brachysoma, R. fauhni*	Pelagic	Their food consists of phytoplanktons and zooplanktons. The phytoplanktons comprise the diatoms represented chiefly by *Coscinodiscus, Pleaurosigma, Chaetoceras, fragillaria, Thalassionema, Skeletonema, Thalassiothrix, Biddulphia, Dipnophysis,* etc. The zooplanktons belongs to varied groups of organisms; the crustaceans form the major portion, with copepods in high percentage. The Indian mackerel is a surface feeder.
8	Nemipteds	*Nemipterus japonicus* and *N. bleekeri*	Demersal	They are bottom living. They feeds on a wide range of bottom living animals, invertebrate worms, chytocerous, mussels, cephelopods and fishes. The diet changes litle with size. They are benthic feeder.
9	Carangids	*Decapterus russelli, Caranx elampygus, C. carangus*	Columner/demersal	Food of *Decapterus russellii* is mostly clupeoid fish, some diatoms, copepods and other crustaceans. The juveniles feed on acetes and copepods. Food of *Caranx melampygus* is mostly copepods and crustaceans and larval fishes while food of *Caranx carangus* is stomatopod larvae, crustaceans and polychaete worms. *Alectis indicus* (Thradfin Trevelly) feed zoea larvae, amphipods, cirripede larvae and copepods. They are bottom cum column feeders.

resources remain largely indiscernible in the light penetrating zone of the water column. Food and feeding habitats play a key role in the distribution of resources. Congregation of food in different habitats (surface, water column and seabed) controls the distribution of fish population. The production and congregation of food resources at surface and subsurface depths can be easily detected by the ocean colour sensor as it has the capability to look into the sea. The ocean colour sensor can detect the radiation backscattered from one attenuation depth in the water column. This helps to locate sites of enhanced production available as food to the resources in the habitat zones. Habitat of fishery resources also depends on a physiologically suitable environment. Satellite-derived SST partially explains the environmental suitability to fish with reference to their physiology. Fishery resources of benthic zones depend on the food resources available on the sea floor, detritus material, vertically migrating plankton and other marine living resources. Hence, wherever surface and water column production is higher, the probability of available food resources at different trophic levels including benthos is comparatively higher. The majorities of species in PFZs are primary, secondary or tertiary consumers feeding on different stages of the life cycle of prey, except herbivorous species like sardines and mackerels. This indicates the high ecosystem diversity, i.e. variations in communities of species within an ecosystem and high physiological diversity, i.e. variations in feeding, reproduction and predator avoidance strategies within the community. The high ecosystem diversity reflects availability of a wide variety of ecological niches. High physiological diversity reflects a greater ability of the community within an ecosystem to adjust to the environment. High species and physiological diversity in an ecosystem are indicators of a healthy ecosystem. Hence, the ecosystem of PFZs is stable, yielding high CPUE.

6. Conclusions

A satellite-based PFZs forecast methodology for different fishery resources has been proposed. Species diversity and their per cent contribution were evaluated in the PFZs using fish catch data by bottom trawling conducted during validation experiments. Habitat and food of dominant species were linked with satellite-derived biochemical and physical parameters. The per cent contribution of pelagic and water column species was fairly high, as compared to demersal species. The contributions of catfishes in PFZs were found to be significant though they are a demersal species. The species investigated were found to be distributed as per the availability of food and feeding habitat. The technique is comparatively more suitable for pelagic and water column species as compared to demersal resources, especially for deeper water areas beyond the zone of light penetration. In general, higher catches and species diversity in the ecosystem was observed in the study area.

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