Indian J. Fish., 63(1) : 8-15, 2016
DOI: 10.21077/ijf.2016.63.1.44455-02

Validations on satellite based potential fishing zone advisories along Goa, south-west coast of India

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ABSTRACT

The annual harvestable marine fisheries potential of Goa is estimated to be about 1.5 lakh t of which 50% is exploited. Potential fishing zone (PFZ) forecasts based on remotely sensed chlorophyll concentration and sea surface temperature are being applied for harvesting marine fishery resources. In this context, a validation study was carried out to analyse the effectiveness of PFZ advisories for Goa coast by 290 simultaneous purse-seine fishing experiments in PFZ and non-PFZ regions. A total of 290 feedbacks were collected from 290 fishing experiments within and outside the PFZ region with similar capacity vessels during 2006-2012. There was 50% reduction in scouting time for the purse-seine fishing which utilised the PFZ advisories. Purse-seiners were benefitted with a significantly higher ($p<0.01$) mean CPUE (4188.6 kg h^{-1}) and mean profit (₹2.72 lakhs) by fishing in PFZ regions in comparison with the mean CPUE (1783.5 kg h^{-1}) and mean profit (₹0.86 lakh) of non-PFZ regions. It was observed that the CPUE in purse-seine fishery was improved by 2.3 times by using PFZ advisories. Moreover, the benefit cost ratio significantly ($p<0.01$) improved in purse-seine fishing from PFZ regions (2.48) compared to non-PFZ regions (0.79). The species-wise analysis showed that Indian mackerel, Indian oilsardine, horse mackerel and seerfish formed the major species that differentiated the catches from PFZ regions. Thus, it was inferred that the PFZ advisories basically holds good for the pelagic species. The use of oceanographic and plankton data for species-specific forecasts in the future is discussed.

Keywords: Goa, Non-PFZ region, PFZ region, Potential fishing zone, Purse-seine fishing, Validation

Introduction

Goa situated along the south-west coast of India has a coastline of 104 km (1.28% of the Indian coast line of 8117 km) with a continental shelf area of 10,000 sq. km. and the fisheries sector of the state contributes to about 2.5% of the total GDP (Anon., 2012). The estimated marine fish production of Goa during 2012 was 72,307 t, an increase of 23.7% in comparison with 2011 (CMFRI, 2013). The marine fisheries sector of the state contributes about 97% of the total fish production in Goa (Anon., 2012). The mechanised, motorised and artisanal sectors contributed 92.6, 6.8 and 0.6%, respectively of the total catch of the state (CMFRI, 2013). In Goa, the pelagic resources contributed 80% of the total catches. The total fishermen population in Goa is about 10545 (CMFRI, 2012) of which South and North Goa contributes about 64 and 36% respectively. Goa has an estimated marine fisheries potential of 1.14 lakh t per annum (CMFRI, 2002). The total sustainable yield from pelagic and demersal fisheries of Goa is projected to be 46,560 and 67,500 t per annum respectively (Mohanta and Subramanian, 2001). South Goa has a total fleet of 1603 fishing crafts which include 769 mechanised vessels (including trawler, gillnetter and purse-seiner), 708 motorised vessels and 126 artisanal vessels (Table 1). On the other hand, North Goa has a fishing fleet of 1063 fishing crafts which include 373 mechanised vessels, 589 motorised vessels and 101 artisanal vessels. Similarly, a total of 33 fish landing centres spread along Goa with 20 along South Goa and 13 along North Goa. The marine fishing fleet comprises 2666 fishing crafts, of which purse-seines contribute about 12%. The duration of fishing operations ranges from 2 h in case of single day operations to 20 days for voyage fishing with a major portion of time being spent on scouting the fish shoals in fishing grounds. The craft length ranges from 20 to 25 m and the mesh size of purse-seines ranges from 20 to 40 mm (CMFRI, 2012).

Indian National Centre for Ocean Information Services (INCOIS) provides short term fish forecasts using remote sensing (RS) and geographic information system (GIS) techniques (Nayak *et al.,* 2003). The information on chlorophyll, sea surface temperature (SST) as well as direction and magnitude of wind are the basic inputs for generating this PFZ forecasts. The multilingual PFZ

Table 1. Fishing crafts employed in the fishery of Goa

District	Mechanised			Total mechanised	Motorised	Artisanal	Total
	Trawlers	Gillnetters	Purse-seiners				
South Goa	556	12	201	769	708	126	1603
North Goa	278	0	95	373	589	101	1063
Total	834	12	296	1142	1297	227	2666

Source: CMFRI, 2012

advisories are generated every day and disseminated to about 500 fish landing centres/fishing villages covering the entire coast line of India (Grinson *et al.,* 2013).

Validation of PFZ forecasts have revealed significant increase in fish catch along north-west coast of Gujarat (Solanki *et al.,* 2001; 2003; Nayak *et al.,* 2003; Dwivedi *et al.,* 2005) and all over the country (Choudhury *et al.,* 2002). In addition, PFZ validation studies along the island regions such as Andaman and Nicobar has also revealed significantly higher catch from PFZ regions (Grinson *et al.,* 2011; 2013). PFZ validation experiments along Kerala demonstrated significantly higher CPUE and net profit obtained by fishing in PFZ compared to non-PFZ regions (Preetha and Pillai, 2012). PFZ validation experiments along Odisha coast demonstrated significantly higher CPUE and reduction in scouting time in PFZ compared to non-PFZ regions (Sahu *et al.,* 2012). Apart from comparing the catch in PFZ and non-PFZ regions, there were experiments conducted to evaluate the efficacy of various dissemination methods of PFZ advisories in Andaman and Nicobar Islands (Grinson *et al.,* 2014). These experiments validated the speed, spread and accuracy of methods in disseminating the advisories to the fishermen (Grinson *et al.,* 2014). Further, there were some specific experiments carried out to find out trends in PFZ locations especially along Mumbai coast (Kamei *et al.,* 2014). These experiments were conducted to highlight the possible geographical and bathymetric information about the PFZ locations (Kamei *et al.,* 2014).

The present study describes the validation results of the PFZ advisories based on experimental operations and landing centre based surveys along the major fish landing centres in Goa. A quantitative analysis of the benefits in terms of net profit fetched due to the reduction in searching time and higher catch as well as percentage of success in the fishing operations carried out within PFZ and outside PFZ areas is presented.

Materials and methods

Study area and dissemination of PFZ advisory

PFZ forecasts were disseminated in Goa during 2006-2012 using various modes and feedback data were collected in a standard format from fish landing centres (FLCs) of Goa. The study was carried out along the Goa coast, and landing centre based surveys were restricted to the major FLCs of Malim, Vasco and Cutbona. The PFZ maps including technical details such as direction, angle in degrees, distance in kilometres, and depth in metres (depth is demarcated if cloud-free satellite data is available) from the reference points and latitude/ longitude of the fishing grounds to guide the fishers to the PFZs were also provided separately. PFZ forecasts were disseminated through electronic display boards (EDBs) installed at three major landing centres (LC) (Table 2) for disseminating PFZ forecasts and other ocean features in near-real time. The PFZ advisories were based on SST and SSTCH (sea surface temperature and chlorophyll) based maps. Free distribution of PFZ maps to the fishermen and telephone/text/mail messages were also tried for the dissemination of PFZ information. The dissemination was through heads of the fishermen associations and regional staff of the fisheries department.

Data collection and analysis

For conducting the validation experiments, data from similar crafts were compared among the three major FLCs. Purse-seiners were employed for the validation experiments as they are the major fleet operated along the coast. The vessels of 20 to 25 m OAL (overall length) with an engine capacity of 100-150 hp and mesh size of 30-40 mm, operating at depths between 8-231 m were used for the comparative study. A total of 290 feedbacks were collected from 290 fishing experiments within (PFZ) and outside the PFZ (non-PFZ) region employing vessels with similar technical and operational characteristics

Table 2. Particulars of installation of electronic display boards (EDBs) at landing centres

Location	GPS co-ordinates	District	Mechanised vessels
Malim	15°30’17.65”N; 73°50’01.47”E	North Goa	350
Vasco	15°24’02.19”N; 73°48’33.38”E	South Goa	235
Cutbona	15°09’24.77”N; 73°57’13.62”E	South Goa	270

during 2006-2012 covering different seasons. Fishermen used GPS and pre-identified reference points to locate the PFZs demarcated in the forecasts.

Major FLCs of Goa were visited periodically and feedback data with respect to fishing grounds, crafts, major species landed, catch per unit effort (CPUE) (kg h^{-1}), mean length of the catch and economics of fishing operation were collected using pre-tested questionnaires prepared for the study. The benefit-cost analysis was carried out considering all the possible operational expenses (including operational part of fixed expenses) encountered by the boat owners including the maintenance charges worked out on an average for an operation.

The mean CPUE and mean profit obtained in the PFZ validation experiments were compared with the non-PFZ regions. Profit was calculated by subtracting the cost of fishing from returns. Beneift-cost ratio was worked out by dividing the total returns with total cost involved in a fishing operation. However, the apparent cost of generation of PFZ advisories is not considered in the cost of fishing. Year, month and landing centre were the major factors used for comparing the observations from PFZ and non-PFZ regions.

There are basically three seasons based on the south-west monsoon in Goa: south-west monsoon (June to September), post-monsoon season (October to January) and pre-monsoon season (February to May). The seasonal patterns in mean CPUE and mean profit were analysed separately for PFZ and non-PFZ regions. Apart from these, the diversity of species landed, mean CPUE and mean profit for different species in PFZ and non-PFZ regions were also compared. All statistical comparisons were carried out using independent 't' test for PFZ and non-PFZ regions using SAS 9.3 version (SAS, 2012).

Results and discussion

Analysis of data from the feedback information collected showed that the technology was effectively disseminated to the fishermen. The forecasts were not disseminated during the trawl ban period. Due to non-availability of cloud free data, the number of PFZ advisories during second half of the year was less in comparison with the first half especially during monsoon season. Therefore, the number of feedbacks obtained during monsoon season was less in comparison with other seasons. During the period from 2006-2012, a total of 166 advisories were validated with 290 feedbacks out of 400 advisories received. Thus, validation of 41.5% of the received forecasts was accomplished during the study period. About 24% of the active fishermen used PFZ advisories out of the total 740 (Table 3). There was 50% reduction in scouting time for purse-seine fishing which utilised the PFZ advisories. The purse-seiners were benefitted with a significantly higher ($p<0.01$) mean CPUE (4188.6 kg h^{-1}) and mean profit (2.72 lakhs) by fishing in PFZ regions in comparison with the mean CPUE (1783.5 kg h^{-1}) and mean profit (₹0.86 lakh) than in non-PFZ regions. Thus, it is observed that the CPUE in purse-seine fishery was improved by 2.3 times by using PFZ advisories. In the current validation experiments, Indian mackerel (46%), Indian oilsardine (24%) and seerfish (10%) were found to be the major catch and contributed about 80% of the total catch. In the following sections, fishing operations in PFZ and non-PFZ regions in terms of CPUE, profit and benefit-cost ratio is compared.

CPUE

Observations from the validation experiments showed that there is a significant difference ($p<0.01$) in CPUE between non-PFZ and PFZ regions with respect to year, month and landing centre. The PFZ regions showed significantly greater CPUE ($p<0.01$) in comparison with the non-PFZ regions with respect to all these factors (Fig. 1). It is revealed that the year 2008 represented the highest catch rate (mean CPUE = 5850 kg h^{-1}) and the year 2012 represented the lowest (mean CPUE=-2367.7 kg h^{-1}) from PFZ regions. Moreover, there was a decrease in catch rate in PFZ regions from 2006 to 2012. Among landing centres, Malim, Vasco and Cutbona stood in the ascending order of mean catch rates which were 3223.21, 3797.73 and 3979.27 kg h^{-1} respectively in PFZ regions. April, May and June were the months with the highest catch rates and the period from August to January showed similar catch rates in PFZ regions. There was a decline in mean catch rate from January to March in PFZ regions.

Table 3. Particulars of fishermen using PFZ information in the major landing centres

Landing centre	Number of active fishermen	Number of PFZ users	Percentage
Malim	200	52	26
Vasco	290	71	24.5
Cutbona	250	55	22
Total	740	178	24

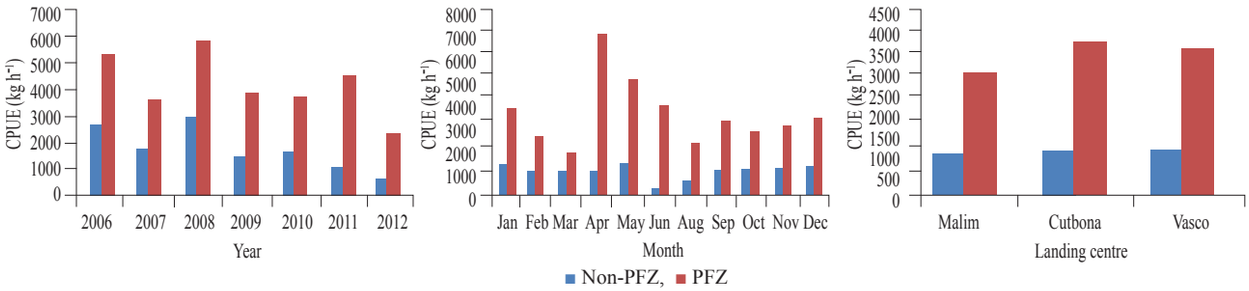

Fig. 1. CPUE (kg h^{-1}) obtained (a) Year-wise, (b) Month-wise and (c) Landing centre-wise during the PFZ validation experiments along Goa

Profit and benefit-cost ratio

There was a significant difference in profit between PFZ and non-PFZ regions with respect to year, months and landing centre. The PFZ regions showed significantly higher profit ($p<0.01$) in comparison with the non-PFZ regions with respect to all the factors (Fig. 2). The year-wise analysis showed that the mean profit was maximum (₹5.83 lakhs per operation) during 2006 which was followed by a drastic decrease in mean profit in 2007 in PFZ region. Further there was a gradual increase in the mean profit from 2008 to 2012 in PFZ region. Among landing centres, vessels along Malim, Cutbona and Vasco stood in the ascending order of mean profits of ₹2.41, 2.76 and 2.84 lakhs respectively in PFZ regions. The period from April to October showed higher mean profit in comparison with the period from November to March in PFZ regions. The average cost of purse-seine fishing operations during the study period was ₹1.12 lakhs. The mean benefit-cost ratio was significantly higher ($p<0.01$) for purse-seine fishing in PFZ regions (2.48) in comparison with non-PFZ (0.79) regions (Table 4).

Species

The diversity of species in the fish catch was also different among PFZ and non-PFZ regions (Table 5). Major species obtained from the PFZ regions were Indian mackerel, Indian oilsardine, horse mackerel, seerfish, coastal tuna, lesser sardines and yellowfin tuna. These species were abundant in catches from PFZ regions. There were also incidental catch of skipjack tuna, scads, white sardine, shrimps, silver pomfrets and

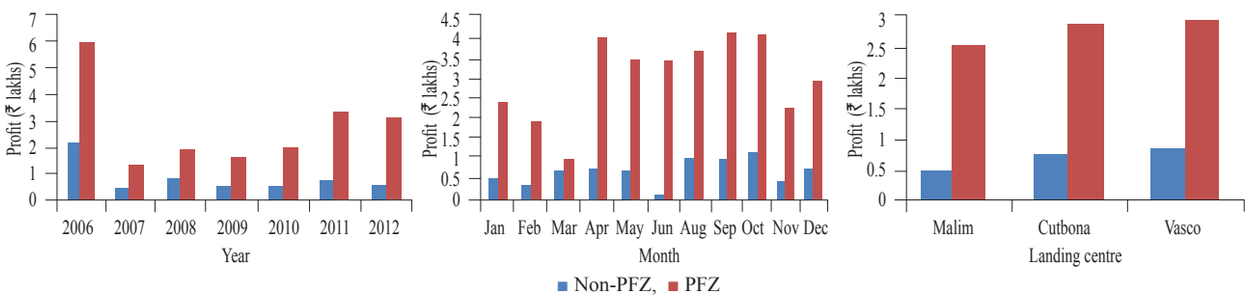

Fig. 2. Profit (₹Lakhs) obtained (a) Year-wise, (b) Month-wise and (c) Landing centre-wise, during the PFZ validation experiments along Goa

Table 4. Year-wise average cost per operation and benefit-cost ratio in PFZ and non-PFZ regions

Year	Average cost per operation (₹ Lakhs)	Benefit-cost ratio (Non-PFZ)	Benefit-cost ratio (PFZ)
2006	1	2.15	5.84
2007	1.1	0.44	1.24
2008	1.1	0.76	1.71
2009	1.15	0.53	1.44
2010	1.15	0.50	1.70
2011	1.15	0.66	2.86
2012	1.2	0.52	2.57

Table 5. Month-wise major species observed in fish catch from PFZ and non-PFZ regions

Month	Species	
	Non-PFZ	PFZ
January	M, OS, HM and SR	M, OS, HM, YFT, CT, LS and SJT
February	M, OS and HM	M, CT, OS, HM, LS and SR
March	OS, M, HM and SR	OS, M, CT, HM and SR
April	OS, M, P and CT	OS, M and CT
May	M, OS and HM	M, OS, HM, CT and W
June	M and OS	M, OS and HM
July	.	.
August	M, SR, OS and SH	M, SR and SH
September	M and SR	M, SR and P
October	M, SR, OS and HM	SR, M, OS, BP, HM, SJT and SC
November	M, OS, HM, SR and CT	M, OS, SR, CT, HM and LS
December	M, OS, SR, CT, HM and P	M, OS, SR, HM and CT

M-Indian mackerel, OS-Indian oilsardine, SR-Seerfish, HM-Horse mackerel, P-Pomfrets, CT-Coastal tuna, SH-Shrimps, YFT-Yellowfin tuna, LS-Lesser sardine, SJT-Skipjack tuna, W-White sardine, BP-Black pomfret and SC-Scad

black pomfrets. Yellowfin tuna and skipjack tuna were not found in non-PFZ regions.

The upwelling fronts and eddies in the ocean support the aggregation of pelagic fishes (Solanki *et al.,* 2001, 2003, 2005; Nayak *et al.,* 2003) as they are linked to phytoplankton in the oceanic food web (Ware and Thomson, 2005). Our present study also confirmed that the PFZ advisories were useful in getting significantly higher ($p<0.01$) catches of pelagic fishes like Indian mackerel, Indian oilsardine, horse mackerel and seerfish (Table 5). Total number of species in the PFZ region was thirteen and that from the non-PFZ region was only seven.

The PFZ regions showed significantly higher ($p<0.01$) CPUE and profit in comparison with the non-PFZ regions for major species (Fig. 3). Maximum

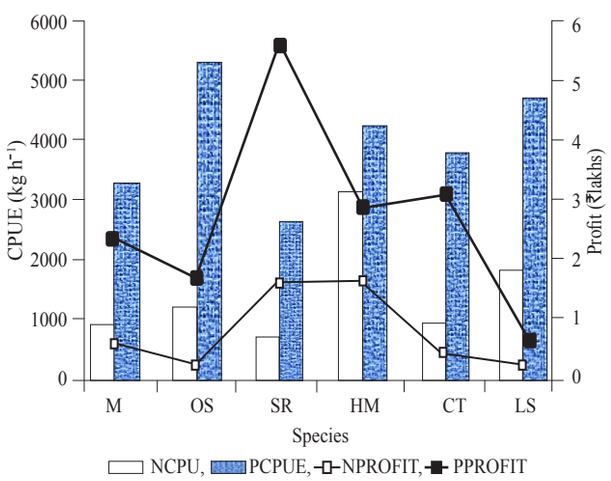

Fig. 3. Species-wise mean CPUE and mean profit obtained during the PFZ validation experiments along Goa (Prefix 'N' and 'P' correspond to non-PFZ and PFZ respectively)

mean CPUE was for oilsardine while the maximum profit was for seerfish. Similarly, the minimum mean CPUE was for seerfish and minimum profit for lesser sardines. Thus, species-wise analysis in the validation experiments confirmed that the PFZ advisories have benefitted the fishermen by giving higher catches of low value pelagic species and moderate catches of high value pelagic species.

Season

The PFZ regions showed significantly higher ($p<0.01$) CPUE and profit in comparison with the non-PFZ regions for different seasons (Table 6). In PFZ regions, the maximum mean CPUE was during pre-monsoon while the maximum profit was during monsoon (Fig. 4). Similarly, the minimum mean CPUE was during monsoon and minimum profit was during pre-monsoon. The PFZ validations during monsoon revealed that more number of validations experiments landed mackerel, seerfish and oilsardine. Similarly validation experiments during pre-monsoon season landed mainly mackerel, sardine, coastal tuna and horse mackerel. These low value species were landed in large quantities during pre-monsoon, while mackerel and seerfish were landed significantly during monsoon. These might have resulted in the high mean profit during monsoon and high mean CPUE during pre-monsoon season. While comparing the mean length of the catch in various seasons, it is observed that the length of the fish were also significantly higher ($p<0.01$) in PFZ regions compared to non-PFZ regions.

Potential fishing zone forecasts are found to be a good tool in the exploitation of marine fisheries resources. (Nayak *et al.,* 2003). The field experiment studies showed that the PFZ advisories reduce the operational costs.

Table 6. Season-wise major species observed in fish catch from PFZ and non-PFZ regions

Season	Species	
	Non-PFZ	PFZ
Pre-monsoon	M (712.31, 19.31), OS (971.88, 15.46), HM (4625, 24.43) and LS (1850, 15.78)	M (3312.86, 19.15), OS (6423.96, 15.56), CT (3788, 47.98), HM (5123.08, 23.3), LS (4250, 13.69), SR (3750, 87.13)
Monsoon	M (957.86, 17.58), SR (613.33, 46.22) and OS (773.33, 16.9)	M (3332.26, 17.76), SR (2441.18, 46.25) and OS (4666.67, 17.77)
Post-monsoon	M (1168.67, 19.34), OS (1814.67, 16.35), SR (2441.18, 46.25) and HM (2220, 19.03)	M (3253.21, 19.48), OS (4513.33, 16.1), SR (2604.39, 39.59), HM (3940, 19.29), CT (3863.33, 41.29) and YFT (3500, 26.35)

M-Indian mackerel, OS-Indian oilsardine, SR-Seerfish, HM-Horse mackerel, P-Pomfrets, CT-Coastal tuna, SH-Shrimps, YFT-Yellowfin tuna, LS-Lesser sardine, SJT-Skipjack tuna, W-Whitefish, BP-Black pomfret, SC-Scad. Parentheses: [Mean CPUE (kg h^{-1}) and Mean total length (cm)]

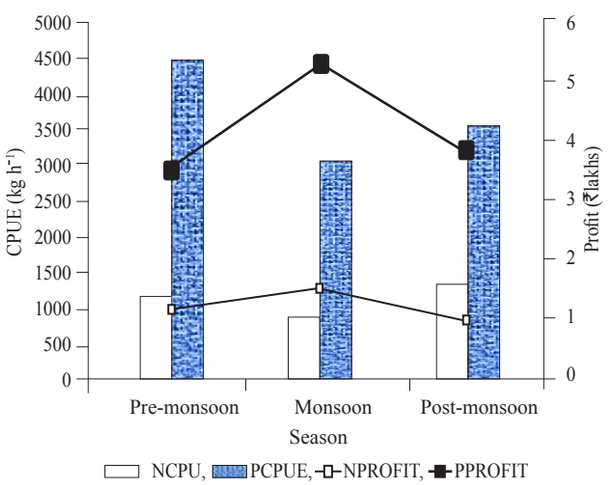

Fig. 4. Season-wise mean CPUE and mean profit obtained during the PFZ validation experiments along Goa (Prefix 'N' and 'P' correspond to non-PFZ and PFZ respectively)

PFZ validation studies along the north-west coast (Solanki *et al.,* 2001, 2003; Kamei *et al.,* 2014), south-west coast (Preetha and Pillai, 2012), south-east coast (Nammalwar *et al.,* 2013), north-east coast (Sahu *et al.,* 2012) and Andaman and Nicobar Islands (Grinson *et al.,* 2011, 2013, 2014) showed significantly higher ($p<0.01$) catches from PFZ notified region in comparison with non-notified regions. In this context, results of the present study indicate that satellite based precision fishing is really beneficial to the fishermen. Being a tourist destination, Goa holds huge potential for marketing and trade of marine fishery resources. The method of satellite based fishing will help in realising better profits for fishermen as a result of reduction in operational costs and partially due to the capture of high value species.

Validation studies on the PFZ advisories are less along the south-west coast (Preetha and Pillai, 2012). This study has compared the catch rates and net profit in PFZ and non-PFZ regions on the basis of season, species and landing sites and supplements information to the validation studies from this particular region.

Fishes are assumed to respond with variations in temperature and food availability (Nammalwar *et al.,* 2013). Oceanographic features such as fronts and eddies simulate primary productivity and attract pelagic planktivorous fish species (Anand *et al.,* 2014). Thus, it is understood that fishes congregate in the thermal fronts, upwelling zones and mesoscale eddies (Anand *et al.,* 2014). Aggregation of planktivorous fish species further draw their predators to these regions (Laurs *et al.,* 1984; Fiedler and Bernard, 1987; Seki *et al.,* 2001). Fishermen also try to identify the periods of these phenomenon to receive higher fish catch rates (Bertrand *et al.,* 2002). PFZ advisories on the basis of satellite derived bio-optical parameters such as chlorophyll and SST is validated as a successful tool in satellite based precision fishing (Nammalwar *et al.,* 2013.). However, the disadvantage of the present prediction is the absence of advisories during the overcast days. In this regard, apart from the bio-optical variables like chlorophyll and SST, recently, satellite based altimetry is used to estimate sea surface height (SSH) and anomalies. Information on SSH and anomalies will be helpful in predicting the mesoscale features, meanders, frontal zones and upwelling regions (Anand *et al.,* 2014). Hence, identification and forecasting these oceanographic features will help the fishermen to find the fish aggregation zones. Satellite aided remote sensing technology is found to be a good tool in the prediction of these features. Therefore, integration of the SSH and other oceanographic variables into the PFZ prediction will give more accurate predictions of fish aggregation zones. However, continuous validation studies are essential with any advisory services. Thus, further validations studies can be proposed including other satellite derived oceanographic features to get a more powerful fish forecasting system which in turn will help in sustainable exploitation of the harvestable potential of fisheries resources.

Acknowledgements

The authors place on record, their thanks to Dr. S. S. C. Shenoi, Director, Dr. Radhakrishnan, Former Director and Dr. Sailesh Naik, Secretary, Dept. of Ocean Sciences, Dr. T. Srinivasa Kumar, Head, ASG, Dr. Nagaraja Kumar, Scientist-in-Charge, PFZ Mission and the entire team of INCOIS, Hyderabad, Ministry of Earth Sciences, Govt. of India, for the funding of the programme of study, constant support and day to day transmission of the PFZ forecast.

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Date of Receipt : 30.10.2014
Date of Acceptance : 16.11.2015