A TECHNICAL ASSESSMENT OF THE USE OF CURRENT GEOSPATIAL TECHNOLOGIES TO DERIVE MARINE FISHERY ADVISORIES IN INDIA AND THE WAY FORWARD

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KEY WORDS: Remote Sensing, INCOIS, PFZ, OSF, CPUE.

ABSTRACT: In India, marine fishers traditionally relied on the various indicators of marine features such as, temperature and colour breaks, feeding patterns of birds, foaming of the sea surface, accumulation of floating objects, etc. Since these parameters are not based on any scientific inputs directly related to fish accumulation, they often led to inaccurate predictions in detecting the potential aggregation zones. Further, the unpredictable weather conditions in the Bay of Bengal and the Arabian Sea due to periodic tropical cyclones, storm surges, high waves etc., impact the lives and livelihoods of the marine fishers. In order to reduce the uncertainty and risk in the marine fisheries sector for better livelihoods of the marine fishing community, the Government of India emphasizes the use of scientific and technology-driven advisories provided by the India National Centre for Ocean Information Services (INCOIS) in the form of the satellite-derived potential fishing zone (PFZ) and ocean state forecast (OSF) advisories. . The basic inputs for the PFZ advisory include Sea Surface Temperature (SST) and chlorophyll (Chl-a), while OSF is derived using the Regional Ocean Modeling System (ROMS) and General NOAA Oil Modeling Environment (GNOME) etc. To identify the PFZ, remotely sensed data of SST and Chl-a retrieved from the thermal infrared channels of National Oceanographic Aerospace Administration-Advanced Very High-Resolution Radiometer (NOAA-AVHRR) and Eumetsat's Met-Op, and optical bands of Indian Remote Sensing Satellite P4 Ocean Colour Monitor (IRS-P4 OCM) and Moderate Resolution Imaging Spectroradiometer (MODIS-AQUA) data are used. As marine fishes are aggregate in the biologically productive regions where favourable sea temperature exists for their survival, the combined use of Chl-a and SST can be used to delineate PFZ and to generate advisories. On the other hand, the OSF advisories provide a greater sense of security to them and their family helping them to avoid fishing during periods of weather extremities. The use of PFZ and OSF advisories not only enables the marine fishers to increase their catch per unit effort (CPUE) but also facilitates sustainable fishing operations by minimizing fuel consumption of boats venturing into the sea. The present study provides a technical overview of the inputs for the geospatially derived advisories in use and the advantages provided by the selected datasets in identifying the PFZ in the Indian Oceans. From the perspective of recent global developments in the geospatial data acquisition and processing, the present work further provides a critical review of the use of available geospatial datasets and data products which can be useful in enhancing the accuracy of PFZ for marine fishing of India.

1. INTRODUCTION

In recent years, marine fishery advisories (MFAs) have emerged as primary resources for planning and executing sustainable marine fishing programmes, as well as, to achieve high socio-economic development of the marine fishers throughout the world. In case of India, more than four million marine fishers from nine maritime states and four union territories (UTs) along 8,118 km long coastline are dependent on the marine fishery sector (CMFRI, 2010; DADF, 2019). In the post-colonial era, the Government of India upgraded the fishery services to ensure food security and generate employment opportunities (Singh & Patnaik, 2014). However, the lack of scientific techniques to delineate fish aggregation, as well as unreliable information on the weather conditions, posed challenges for the profitable development of marine fisheries in India (Miguel and Santos, 2000; Balasubramanian, 2015). In order to reduce the uncertainty as well as risk during all stages of marine fishing operations and to ensure better livelihoods of the fishing community, scientifically generated data by leveraging geospatial technologies came to the fore. Earlier, National Remote Sensing Agency (NRSA) generated PFZ advisory using only NOAA-AVHRR produced SST data during 1996-97 while, the Space Application Centre (SAC) of Indian Space Research Organisation (ISRO) developed a technique to generate PFZ advisory using both SST and Chl-a after the successful launching of IRS-P4 (Oceansat-I) in May 1999. Thereafter, the entire procedure related to development and dissemination of MFAs i.e., PFZ, was streamlined by the Earth System Science Organization-Indian National Centre for Ocean Information Services (ESSO-INCOIS) in late 2001 (Chakraborty et al., 2019). At present, INCOIS disseminates PFZ advisory to all the marine fishing community on a daily basis through various information and communication-based technology (ICT) except fishing ban period associated with the breeding period of fishes (ESSO-INCOIS, 2020).

The PFZ advisory helps the fishers to locate large fish aggregation zone in the open sea while minimising the searching time and hence, the fuel consumption (MSSRF, 2014b, 2014a). As marine fishes are available in the biologically productive regions where favourable sea temperature exists for their survival, the basic inputs for the PFZ advisory include Sea Surface Temperature (SST) and chlorophyll-a (Chl-a). Chl-a concentrations, being the primary photosynthetic pigment in phytoplankton, indicate their relative abundance across the different oceanic regions. In response to changes in SST, the phytoplankton migrate to regions with other favourable environmental conditions in terms of dissolved oxygen (O_2) levels, salinity etc (Tummala et al., 2008). As the fish are dependent on the phytoplankton for their food, they tend to prefer regions with dominant phytoplankton abundance indicated by the presence of Chl-a along with favourable SST. In this context, SST and Chl-a are the most useful environmental indicators to prepare the PFZ advisory, especially for pelagic fishes (Nayak et al., 2007). Presently, the satellite-derived SST data are retrieved from the thermal-infrared channels of National Oceanographic Aerospace Administration-Advanced Very High-Resolution Radiometer (NOAA-AVHRR and Eumetsat's Met-Op (ESA), while Oceansat-II (India based) and Moderate Resolution Imaging Spectroradiometer (MODIS-AQUA) are used to fetch the Chl-a data in the process of PFZ area identification over the Bay of Bengal (BoB) and Arabian Sea regions (ESSO-INCOIS, 2020). Therefore, the present study has been planned to provide a technical review of the satellite-derived PFZ advisory in terms of basic inputs of the advisory, the physical mechanism behind the processing of this advisory along with the benefits of the advisory in the Indian context.

2. STUDY REGION

The coastal regions of India which contribute significantly to the maritime economy largely via fishing, have been considered as the study area for the present study which includes nine maritime states and four union territories (UTs; Figure 1). Geographically, the maritime states and

UTs of India are located in between 6⁰ north latitude to 28⁰ north latitude and 68⁰ east longitude to 94⁰ east longitude. The maximum species diversity comes from the states of Tamil Nadu and Kerala (735 species) while the bulk landings (63%) come from the southeast and northwest coastal regions of India (DARE-ICAR, 2018). On the other hand, the east coastal region only shares 25 per cent to the total marine fish landings in India (MSSRF, 2020).

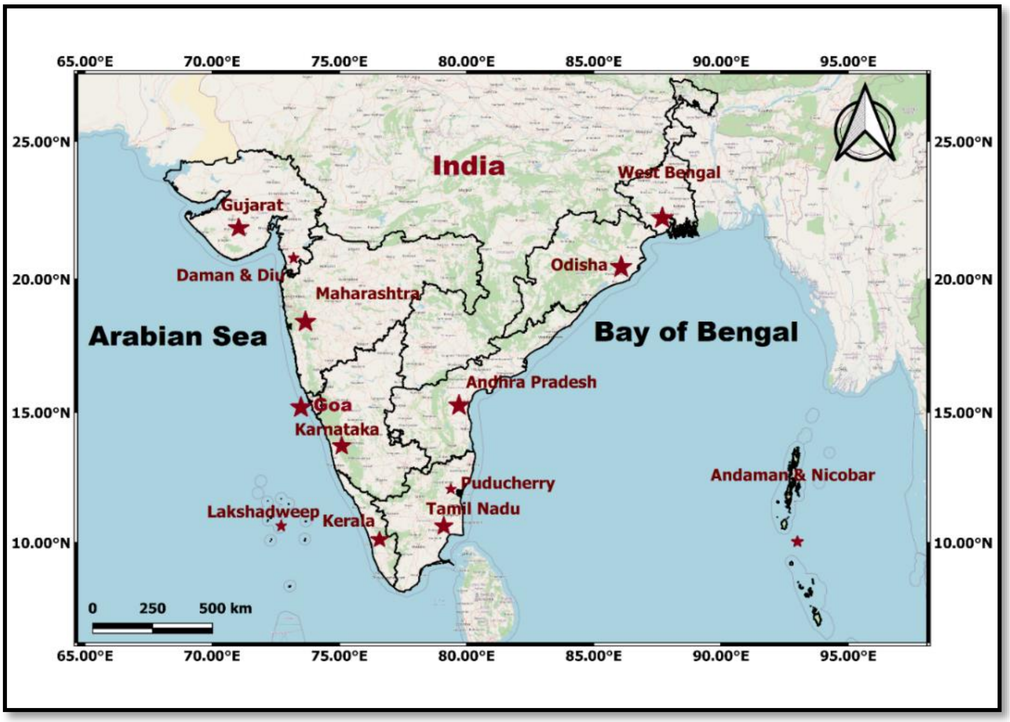

Figure 1: *Study area map of nine maritime states and four union territories (UTs) of India; star marks indicate the location of these respective states and UTs.*

It has been estimated that the total net economic benefits accrued due to the use of PFZ advisories lie in the range of ₹34,000 crores to ₹50,000 crores (NCAER, 2010) over the study region shown in Figure 1. From the perspective of eco-sustainability, such advisories have the potential for saving fuel consumption of motorised boats; for example, saving up to one litre of diesel can reduce 2.63 kgs of carbon dioxide (CO_2) emissions (NCAER, 2015). It has been estimated that marine fishers have collectively increased their profit by approximately ₹3,000 crores through the operationalization of coupled ocean and atmospheric state forecasts (NCAER, 2015). Assessments also showed that the GDP from marine fisheries can go up to 7.8 per cent from the current level of 3.9 per cent if the fisheries advisories were uniformly adopted throughout the country (NCAER, 2015). Globally, the United States of America (USA) used remotely sensed data for the first time in the 1970s to develop MFAs, while in India development of PFZ advisory were initiated in early 1990s (Kamei et al., 2014; Balasubramanian, 2015). However, despite the slow progress towards incorporating geospatial data into mainstream fishing practices, the growing reliance of marine fishers on these scientific methods has proven critical to improve the fisheries production. Presently, India earns a significant amount of foreign exchange by exporting seafood which is 10 per cent of the overall export (DARE-ICAR, 2018). Therefore, optimising the use of PFZ and OSF advisories is crucial for marine fishery operations. Thus the extensive studies conducted on behalf of INCOIS (e.g., MSSRF, 2014a, 2014b; NCAER, 2015, 2010) indicate that the marine fishing community can accrue enormous economic benefits by optimising the utilisation of the PFZ advisory on a pan-India basis.

In this connection, from a technical perspective, it is crucial to understand the various physio-biological factors of the geospatial datasets that are used for the development of PFZ advisory, as well as the computational factors which influence the successful use of PFZ advisory in the country as discussed in the subsequent sections.

3. METHODOLOGY USED IN DERIVING THE PFZ ALGORITHMS

3.1 Data sets

The basic inputs for the development of the PFZ advisory include SST and Chl-a as marine fish shoals are attracted to biologically productive areas where the favourable seawater temperatures exist. For the processing and development of the PFZ advisory in India, presently, INCOIS is using the satellite-derived SST and Chl-a data from various satellite products as shown in Table 1.

Table 1: *Details of the datasets used to generate PFZ advisory*

Data used for PFZ advisory	**Details of the satellite**		
	Satellite name	**Respective agency**	**Remarks**
SST	NOAA-AVHRR	NASA, USA	Retrieved from thermal-infrared channels of the respective satellites
	Met-Op	EUMETSAT, ESA	
Chl-a	Oceansat-II	ISRO, INDIA	Retrieved from optical bands of the respective satellites
	MODIS Aqua	NASA, USA	

The polar-orbiting satellite, NOAA was launched in 1978 for the first time wherewith the AVHRR sensor onboard. The AVHRR consists of five channels in the visible, near-infrared and thermal infrared regions of which channels 4 and 5 were placed under thermal-infrared region, for sensing changes in the SST (Gutman et al., 1995). Presently, a NOAA series satellite NOAA-14 is being used for SST data retrieval since 1994. Subsequently, MetOp (Meteorological Operational Satellite), the first polar-orbiting satellite from Europe was operationalised for SST retrieval in 2006, using sensors like AVHRR, provided by NOAA and IASI (Infrared Atmospheric Sounder Interferometer), provided by CNES/EUMETSAT (ESA, 2020b). Oceansat-II is an indigenous satellite launched by the ISRO on September 23, 2009 as the sequel to Oceansat-1 (IRS-P4) that was launched in 1999. Oceansat-II has enhanced application potential for ocean monitoring including the development of better constraints on the regions of phytoplankton aggregation in the ocean (ESA, 2020c; ISRO, 2020). The Chl-a data provided by MODIS AQUA (formerly known as EOS/PM-1) is based on data acquired from the entire Earth Surface through 36 spectral bands every two days. Aqua is a part of the Earth Observing System (EOS) of NASA, launched on October 18, 1999, which has been instrumental in developing PFZ algorithms globally (ESA, 2020a; Feldman, 2020).

3.2 Methodology

The composite image using the combination of remotely sensed data of Chl-a Concentration (CC) and SST is used to provide the PFZ advisory (illustrated in Figure 2). In the context of India, the CC is being calculated from OCM data using Ocean Chlorophyll-2/3 (OC-2/3) algorithm (as expressed in Equation 1) while the Multi-Channel Sea Surface Temperature (MCSST) approach (as shown in Equation 2) is used to estimate SST data (McClain et al., 1985; Solanki et al., 2001; Maity et al., 2013).

$$R = \log_{10}\{\max[(R_{rs}443/R_{rs}547), (R_{rs}448/R_{rs}547)]\}$$

$$a = [0.2424, -2.7423, 1.8017, 0.0015, -1.2280]$$

$$CC = 10^{(a_0 + a_1R + a_2R2 + a_3R3 + a_4R4)} \ldots\ldots(1)$$

Where, R denotes the reflectance in Remote Sensing, 'a' refers to an empirical constant, and CC is Chl-a concentration.

$$MCSST = C_1T_4 + C_2(T_4 - T_5) + C_3(T_4 - T_5)(\sec\theta - 1) + C_4 \ldots\ldots(2)$$

Where, C_1, C_2, C_3 and C_4 are coefficients which vary according to satellite, T_4 and T_5 are 4th and 5th AVHRR channels, respectively while θ indicates the satellite zenith angle and are in K.

The composite image is produced by using the generated Chl-a data along with SST by monitoring the common feature of these (Solanki et al., 2003). Subsequent to the matching of the aggregation characteristics as 'features' derived from both Chl-a and SST these datasets are used to identify the PFZ. In this connection, the shifting nature of the Special Oceanic Processes (SOPs) i.e., upwelling, formation of the eddies, fronts, meanders, etc., is also very significant to understand the influence of wind in accurate identification of the PFZ (Solanki et al., 2005; Kripa et al., 2014). In this way, using the composite data on Chl-a and SST along with SOPs, the PFZ line/curve is delineated.

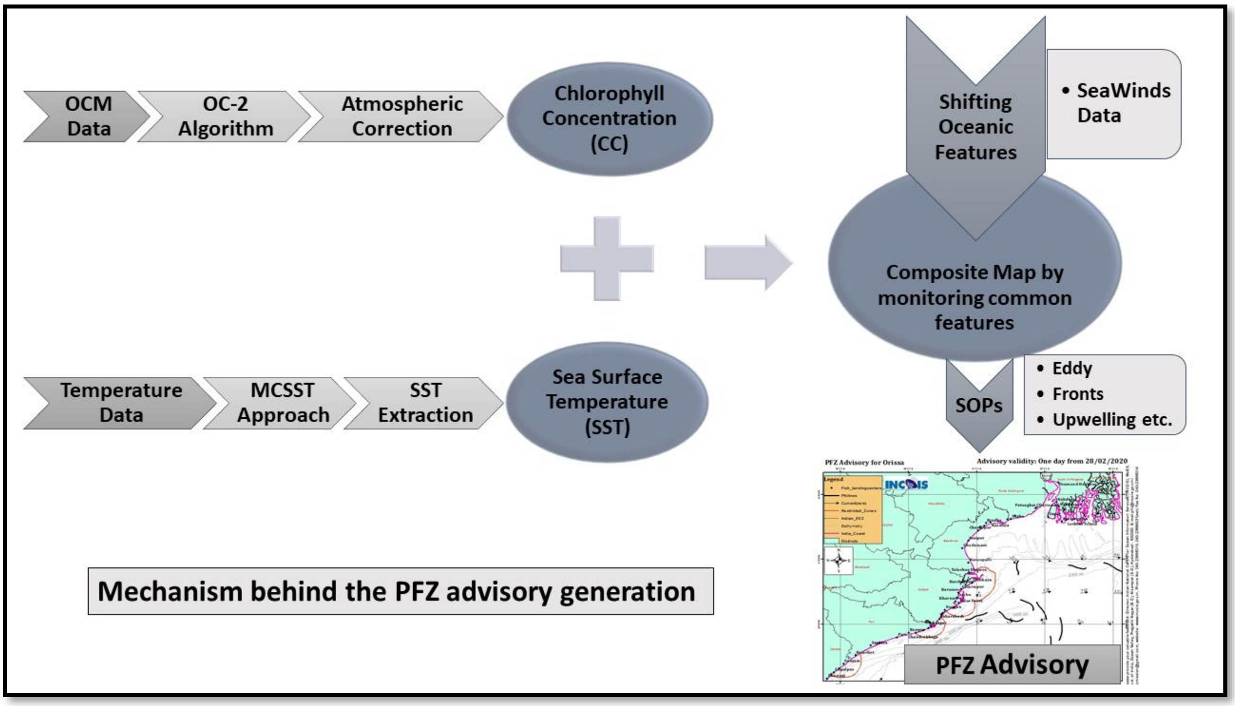

Figure 2: *Methodology adopted to generate Potential Fishing Zone (PFZ) Advisory utilizing chlorophyll and SST data in the Indian context.*

In the subsequent sections, an assessment of the level of 'matching' and combination of the physio-biological factors that attract the fish shoals in the ocean, the resultant mechanism behind the development of the PFZ advisory as well as the benefits of the advisory in the Indian context is provided.

4. RESULTS AND DISCUSSIONS

4.1 Physio-biological factors that determine data availability and accuracy of PFZ

Understanding the biological and physical processes and the interaction between them in the ocean is crucial to track the marine fish shoals (Solanki et al., 2008). As discussed earlier, marine fishes are generally abundant in favourable environmental conditions associated with high phytoplanktonic productivity, SST, seawater salinity, pH, dissolved oxygen etc. (Tummala et al., 2008). Review of the global PFZ algorithms indicate that it is essential to incorporate data on the sharp horizontal temperature gradient, and SOPs like, upwelling zones, location and evolution of frontal boundaries, current eddies etc., which indicate the dominance of marine pelagic fishes (Pillai and Nair, 2010; Mane and Mishra, 2017). Thus, the successful estimation of PFZ seems to rely on the availability of composite data on temperature gradients and SOPs for pelagic studies. Another factor critical to accuracy of PFZ prediction includes the accurate delineation of the SOPs representing high CC, which in-turn indicate high biological productivity (Solanki et al., 2008) are. Therefore, the integration of SST and CC (shown in Figure 3) is more effective for developing PFZ forecast due to their better ability to identify SOPs in the tropical oceans (Mane & Mishra, 2017). A critical factor which constraints the predictive ability of the algorithm pertains to the changing directions of the wind causing a shift in the SOPs and hence, the dispersal of fish shoals in the sea.

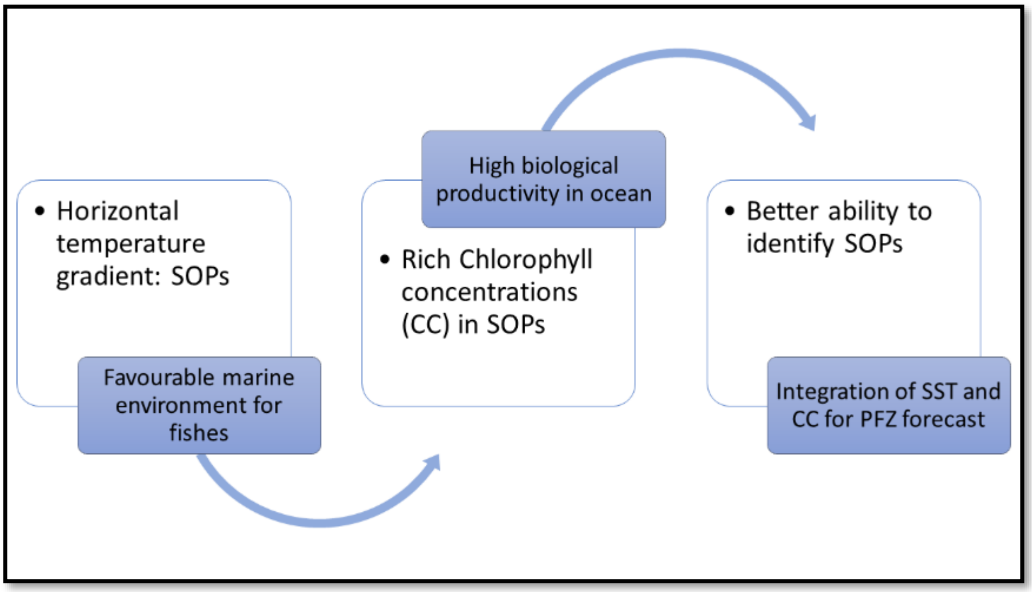

Figure 3: *Schematic representation of physio-biological processes with integrated data on SST and CC which determine the predictive ability of the fish aggregation zones in the sea.*

4.2 Data-based factors affecting the extraction of PFZ

The spatial and temporal resolutions of the satellite-derived SST and Chl-a data are critical factors for determining the PFZ generation as these datasets can be extracted at high repetivity with a large spatial coverage over the ocean. The most important data-based factors thus pertain to the swath and the spectral sensitivity of the sensors which have been enhanced in the recent years, giving rise to better estimates of the PFZ. While it is difficult to achieve both high spatial and spectral accuracy at the same time, a balance of the data available needs to be established to achieve adequate bulk estimates of the phytoplanktonic abundance versus the spectral sensitivity to determine the standing population in the open ocean. The PFZ is also closely associated with the temperature frontal zone of the ocean; availability of thermal datasets that indicate the assembly or dissipation of the phytoplankton can enhance the predictive ability of the PFZ if incorporated into the same. The desired temporal resolution is also a critical factor that determines the prediction of the fish stock are a given location. The duration of time for which the phytoplankton are available at a given location for the fishes to be attracted towards them is a critical factor incorporated into the PFZ advisories. The availability of the temporal information on the PFZ can hence be helpful to plan for successful and sustainable fishing expeditions.

Presently, the satellite-derived Chl-a data with two days repetivity with one km of ground area coverage (GAC) is used for PFZ generation in the spectral ranges of 0.4 to 0.9 µm, while SST data is extracted between 10.3 to 12.5 µm of spectral ranges with 4 km of GAC on a daily basis (ISRO, 2020; Feldman, 2020; ESA, 2020a, 2020b, 2020c).

Swetha et al., (2017) reported that the PFZ lines/curves were delineated through the identification of thermal fronts in the ocean from satellite images. Prior to 2011, vector data of the SOPs were superimposed on the composite data of the SST and Chl-a, and this was highly susceptible to manual error apart from being time-consuming. The subsequent adoption of automated identification methods of the frontal zone has reduced human-induced error and also shortened the operational process-chain. In 2011, ESSO-INCOIS started to develop the PFZ advisory utilizing SST and Chlorophyll from multiple satellite products. ESSO-INCOIS also developed SATellite Coastal and Oceanographic REsearch (SATCORE) programme during 2008-2017 to overcome the difficulties in generating accurate PFZ advisory during cloudy days, especially in the monsoon seasons, which is the peak fishing period, and also to encourage the fishers to carry out only pelagic fishing practices in the deep ocean to avoid operational difficulties due to extreme weather conditions (Chakraborty et al., 2019). Most of the studies reported that low SST indicated high CC, reflecting the enhanced growth of phytoplankton while, a negative relationship was observed between SST and CC (Figure 4). These relationships between the datasets, incorporated into the algorithm further strengthen the overall predictive ability of the PFZ algorithm.

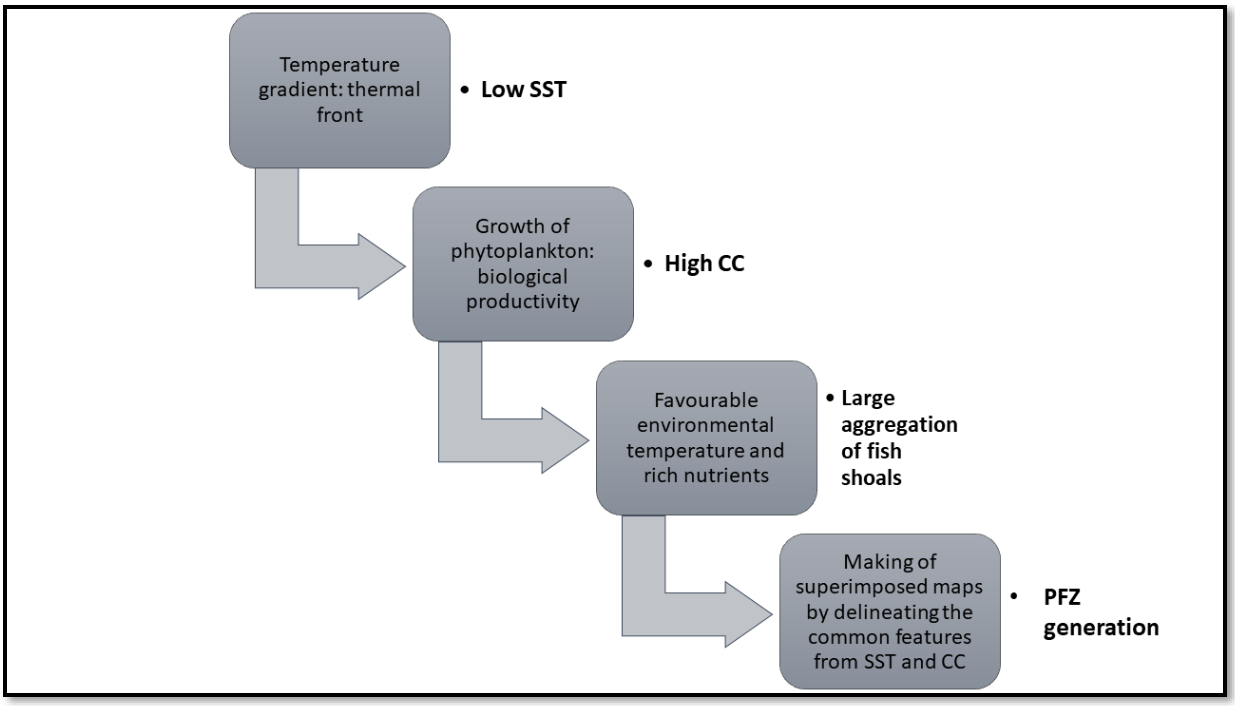

Figure 4: *Combine usages of sea surface temperature (SST) and chlorophyll concentrations (CC) for generating PFZ advisory.*

The combination of SST and CC has been treated as the best inputs to develop PFZ advisory while the data regarding wind movement is crucial to tract the probable shift of the same. Therefore, the composite images of SST and CC in the SOPs are used to utilize in delineating the PFZ lines/curves in the open sea. While the use of PFZ advisory no doubt enhances the CPUE, there exists a scope to incorporate the estimates of least distances to the predicted fish accumulation zones. This can provide additional data for planning travel times and minimising, the search time to reach the PFZ area as well as fuel consumption and carbon-dioxide emissions to the marine environment.

5. CONCLUSIONS

Usages of geospatial technology in the field of MFAs was initiated globally in the 1970s, however, in India, it had been initiated only in the 1990s utilizing only satellite-derived SST data while CC data were included only in 2000s. Presently, INCOIS develops PFZ advisory utilizing multiple satellite products. Although, their predictive accuracies are determined by a combination of both the natural physio-biological characteristics as well as data-based factors identified by the present study. It is important to understand that while shifting dynamics of SOPs influence the accuracy of the predictive ability to a large extent, it is not a trivial task to minimise errors owing to these factors. However, the predictive capabilities of the PFZ advisory can be enhanced by using an appropriate combination of observational and computational enhancements to the datasets by selecting appropriate data resolutions and analytical methodologies to compute the spatial constraints of SST, Chl-a under different climatic conditions. Optimal utilisation of accurate PFZ advisory provides immense opportunities to increase the net profit earned by the marine fishers. On one hand, it is useful for strengthening the economy of the fishing sector by enhancing the overall net profit while simultaneously reducing marine pollution and lowering carbon-dioxide emissions, thereby contributing to sustainable fishing practices. Thus, the scientific enhancement and utilization of PFZ advisory throughout the country are vital for achieving the sustainable development goal 14 (SDG 14) under the agenda 2030, derived by the United Nations in India. Therefore, INCOIS is implementing various scientific innovations such as GEMINI receivers for fishing boats and is also planning to develop species-specific marine fishery advisories in the upcoming years. However, it is essential to consider the technical factors that decrease the accuracy of PFZ advisory as discussed here by leveraging advancements in geospatial technologies as well as computational methodologies to enhance India’s maritime economy and facilitate sustainable fishing practices in India.

ACKNOWLEDGMENTS

The present work forms a part of the survey of literature and methodology for studying the Potential Fishing Zones in India as a part of a research project from Ministry of Earth Sciences, Government of India (Grant No. MoES/16/15/2011-RDEAS(NIAS)).

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