Indian J. Fish., 69(2): 19-29, 2022
DOI: 10.21077/ijf.2022.69.2.111169-03

Habitat suitability of Indo-Pacific sailfish *Istiophorus platypterus* (Shaw, 1792) in the Arabian Sea

S. SURYA[1*], R. PRATHIBHA[2], E. M. ABDUSSAMAD[3], T. L. ASHA[4], B. SANTHOSH[1], B. B. NAYAK[4], R. KARANKUMAR[4], K. G. MINI[3], J. H. KINGSLY AND M. K. ANIL[1]
[1]*Vizhinjam Regional Centre of ICAR-Central Marine Fisheries Research Institute, Vizhinjam, Thiruvananthapuram - 695 001, Kerala, India*
[2]*Mangalore Regional Centre of ICAR-Central Marine Fisheries Research Institute, Mangaluru - 575 001, Karnataka, India*
[3]*ICAR-Central Marine Fisheries Research Institute, Ernakulam North P. O., Kochi - 682 018, Kerala, India*
[4]*ICAR-Central Institute of Fisheries Education, Versova, Mumbai - 400 061, Maharashtra, India*
e-mail: revandasurya@gmail.com

ABSTRACT

Istiophorus platypterus (Shaw, 1792) is the most common billfish species in the Arabian Sea and contributes more than 50% of the total billfish landings in India. The abundance of *I. platypterus* was more off Maharashtra and Gujarat in the northern Arabian Sea and in Lakshadweep islands with higher catches during March, April and December. The aim of the study was to predict the suitable habitat of occurrence and potential fishing ground of *I. platypterus* by correlating the spatial catch rates with environmental parameters along the Arabian Sea. Generalised Additive Modelling (GAM) showed significant relationship between the catch and the predictor variables [sea surface salinity (SSS), sea surface temperature (SST), sea surface height anomaly (SSHa), current speed (CS) and chlorophyll (Chl)]. SSS from 32 to 36 ppt had a positive effect on the expected abundance. Similarly, SST showed a positive effect from 25 to 28°C and thereafter had a negative effect on catch rate. The highest catch values associated with the SSHa was >0.4 m and partial effect of SSHa on catch was negative below 0.4 m. Current speed higher than 0.4 m s^{-1} showed negative effects on catch rate and lower Chl-a values which ranged between 0.04-2.14 mg m^{-3} in the study area showed a positive effect. All explanatory variables (SST, SSHa, CS, Chl) except SSS were found to be highly significant covariates ($p<0.01$, $p<0.01$, $p<0.001$ and $p<0.05$ respectively) and 38.2% of variance was explained by the model with these variables. The paper discusses the fishery and trend of billfish landings along the Indian coast in relation to various remotely sensed data and defines the optimum habitat suitability for *I. platypterus*.

Keywords: Additive models, GAMs, Large pelagics, Northern Indian Ocean

Introduction

Identification of favourable habitats for fishes to feed, grow, mature and spawn during their life cycle is essential to plan sustainable management and conservation of fisheries resources (Valvanis *et al*., 2008). The best way to do this is through adoption of an Ecosystem Approach to Fisheries Management (EAFM), the new paradigm supported by Food and Agricultural Organisation of the United Nations (Staples *et al*., 2014). The main objective of EAFM is to move progressively towards an end-to-end ecosystem approach which improves the understanding of the abundance and distribution of exploited fish stocks, to disentangle fishing impacts from environmental drives, and finally to execute effective management options (Botsford *et al.,* 1997; Cury *et al*., 2004; Garcia *et al.,* 2005). An important step towards EAFM is having knowledge about Essential Fish Habitat (EFH). The primary requirement for EFH analysis approach would be to have information on the ocean and its ecosystem, which includes spatial and dynamic ocean data.

The spatio-temporal data gathered through Geographic Information System (GIS), integrating fishery information with marine resources has paved a new way to formulate decision support systems for fisheries development and management. The GIS based life history resource maps depicting the spatio-temporal distribution of juveniles, sub-adults and adults forms the basic database for providing advisories for seasonal closure or effort restriction during spawning season (Dineshbabu *et al.,* 2016). The use of remote sensing technology in the marine environment is a promising tool for environmental monitoring and habitat suitability studies for adopting conservation measures (Turner *et al.*, 2003; Mumby *et al.,* 2004). Satellite based remote sensed high-resolution images provides valuable information on ocean and coastal environments, relationship between fisheries resources and oceanographic parameters and is a better data source for integrating habitat considerations into marine fish population dynamics (Emmanuel *et al.,* 2011). The Satellite Remote Sensing (SRS) data in conjunction with *in situ* data is used as input data for environmental modelling to find the eco-suitability for resources. Oceanographic parameters such as surface temperature, surface salinity, ocean colour, surface height and current speed have been mapped using SRS to analyse the influence of these ocean processes on species distribution and abundance. Earlier studies have clearly indicated that SST, Chl-a, SSS, SSHa, euphotic depth and bathymetry does influence the spatio-temporal distribution and abundance of marine pelagic fishes (Chen *et al.,* 2009; Chang *et al.,* 2012; Yen *et al.,* 2012; Partrizia *et al.,* 2016; Lan *et al.,* 2017; Lee *et al.,* 2018; Azeez *et al.,* 2021).

Billfishes are large predatory fishes found in all oceans in tropical and sub-tropical waters. A total of twelve true billfish species are reported under five genera and two families (Nakamura, 1985). Collete *et al*. (2006) placed the group in a separate suborder Xiphioidei which was characterised by elongated premaxillary bill or rostrum in adults, dorsal-fin origin over the back of the head, first dorsal lacking true spiny rays, presence of two anal fins, low pectorals on the body, inferior mouth, pelvic fins with one spine and two rays or reduced, isthmus free gill membranes and 24-26 vertebrae. Nelson (2006) had recognised three genera under the family Istiophoridae. *Istiophorus* characterised by a sail-shaped dorsal fin which is taller than body depth and very long pelvic fins. *Tetrapturus* noted by dorsal fin height higher than that of body depth and *Makaira* distinguished by the reduction in first dorsal fin height as not as high as the body depth. While Collette *et al*. (2006) and ITIS (2008) divided Istophoridae into five genera: *Istiophorus* (sailfish), *Istiompax* (black marlin), *Makaira* (blue marlin), *Tetrapturus* (spearfishes) and *Kajikia* (striped marlin). A total of 10 species of billfish have been identified under six genera and two families. A targeted fishery for billfishes does not exist along the Indian coast (Bishnupada and Mathew, 2014); however, billfishes are an important component of the bycatch in longlines, troll and oceanic drift gillnet fishery. Billfishes are unique among teleost fishes in thermal conservation (Worm *et al*., 2005) and have specific habitat preference relative to different oceanographic parameters (Su *et al*., 2011; Nima *et al*., 2018). The distribution, reproductive and feeding biology as well as some molecular genetics of *I. platypterus* have been reported from different oceans (Somvanshi and Varghese 2001; Genoveva *et al*., 2013; Varghese *et al.,* 2013; Bruno *et al*., 2014; Bruno *et al.,* 2018). However, studies on assessing the eco-suitability in the Indian Ocean especially from the Arabian Sea, by using the Generalised Addictive Model (GAM) approach has so far not been reported earlier. The GAM model is widely used as an ecosystem modelling tool (Drexler and Ainsworth, 2013). Hence it was selected for the present study to predict the habitat preference of *I. patypterus.* These models deal with the non-linear relationships between multiple predictors and independent variables (Bellido *et al*., 2001). It is well known that it is difficult to predict the behaviour of a highly migratory fish and to relate its distribution and catch rates to environmental parameters (Romeo *et al*., 2011, 2015; Chiang *et al*., 2015). Billfishes are highly migratory fishes and move freely across the international borders and contribute significantly to catch migratory species of several countries harvested from the high seas (Palacios-Abrantes *et al.,* 2020). The distribution and abundance of billfishes in the Indian seas has been reported by the Fishery Survey of India based on the exploratory tuna longline fishing (Ramachandran and Ramalingam, 2019). The exploratory fishing conducted by M.F.V Yellowfin and M.F.V Matsya Vrushti (2009-18) revealed the presence of billfishes in significant quantities (66%) along the west coast (FAO Area 51) (Ramachandran and Ramalingam, 2019). It is in this context that the present study was limited to observation made along the west coast with special focus on fishery landings made by commercial vessels. The paper attempts to predict the habitat preference of *Istiophorus platypterus* (Shaw, 1792) in the Arabian Sea by fitting a GAM for describing the relationship between catch rates and important oceanographic parameters (SST, SSHa, CS, SSS and Chl). A lot of studies pertaining to the high biological productivity of west coast of India (Panikkar and Jayaraman*,* 1966; Madhuprathap *et al.,* 1996; Solanki *et al.,* 2016) have revealed that, the oceanic attributes favouring fish production such as salinity, temperature, water currents, upwelling, mud bank formation, plankton blooms and phosphate rich coastal water were common in the Arabian Sea. The aim of the study was to predict the suitable habitat of occurrence and potential fishing ground of *I. platypterus* by correlating the spatial catch rates with environmental parameters along the Arabian Sea through the application of GIS, SRS and GAM.

Materials and methods

Study area

Arabian Sea, the north-western boundary of Indian Ocean (FAO Area 51) bordering Indian coastal states of Gujarat, Maharashtra, Karnataka, Kerala, southern Tamil Nadu and Lakshadweep Islands from 7° to 23°N and 60° to 74°E with an approximate area of 0.86 million km^2 constituted the study area (Fig. 1).

Fishery data

The catch data on *I. platypterus* was collected during January to December 2018 from different landing

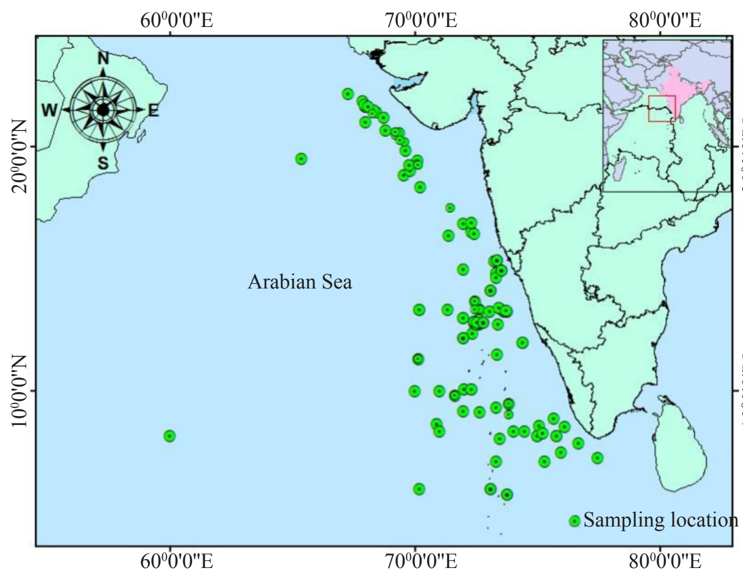

Fig. 1. Fishing locations of *I. platypterus* in the Arabian Sea, covered under this study

centres where the commercial multiday gillnetter cum longliners, operating along the south-west coast of India landed their catch. The monthly catch data of *I. platypterus* was obtained from the Fisheries Resource Assessment Division of ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi, which is estimated using the Multistage Stratified Random Sampling technique (Srinath *et al.,* 2005). This data was supplemented with information on fishing activity, fishing ground attributes, depth of operation, operation days and catch details from logbooks maintained by fishermen and by observing catch onboard fishing vessels at designated landing centres.

Environmental sampling

The oceanographic parameters such as temperature, current speed, chlorophyll, salinity and bathymetry can be integrated into the GIS software routine for correlation studies. The data on SST, SSS, Chl, CS and SSHa were collected from product of the Copernicus Marine Environment Monitoring Service (CMEMS; marine.copernicus.eu) under the Copernicus Marine Service Licence (http://marine.copernicus.eu /services-portfolio/service-commitments-and-licence/). Multiple layers of information in GIS routine help to predict the fishery distribution especially in terms of environmental parameters. To generate the theme map, India's geo referenced base map with World Geodetic System (WGS) coordinate reference system was used and the maps were generated in ArcGIS (Version 10.3, licensed to ICAR-Central Institute of Fisheries Education, Mumbai).

Statistical analysis, estimation of relationship between oceanographic parameters and catch rates of I. platypterus

GAM is a traditional ecological model used to predict the potential fishing grounds of marine fishes (Al-Kharusi, 2008; Brodie *et al*., 2015; Solanki *et al.,* 2016). The predictor variables included in the model were SST, SSS, Chl, CS and SSHa (Table 1). These predictor environmental variables were chosen, as they had wide spatial coverage throughout the study region. The GAM approach (Hastie and Tibshirani, 2017) was used to predict relative abundance of ***I.*** *platypterus* functional groups across the entire fishing locations. The relationship between a response variable (Y) and independent variables (or predictors) is given by the formula:

Y = Link linear predictor (LP) and

$LP = \alpha + \sum fi\ (Xi) + \varepsilon$

where, LP is the linear predictor, the 'link' function is a transformation used to accommodate different response distributions, α is the intercept and ε is the error term. The fi are smooth functions, estimated individually for each predictor (Xi) (SST, SSHa, CS, Chl and SSS). All models were fit using the 'mgcv' package in the R version 4.0.3 environment. The test dataset was used as independent data to predict the catch using the final model constructed with training dataset. Models of catch rates that incorporate relevant environmental variables can be used to infer possible responses in the distribution of *I. platypterus*. These functional relationships can be used to evaluate the impacts of environmental variability on the spatial pattern of *I. platypterus.* The selected model

Table 1. Data sources used in the present study

Parameter	Data source	Resolution
Sea surface chlorophyll	E.U. Copernicus Marine Service Information	0.083° x 0.083°
Sea surface temperature	E.U. Copernicus Marine Service Information	0.083° x 0.083°
Sea surface salinity	E.U. Copernicus Marine Service Information	0.083° x 0.083°
Current speed	E.U. Copernicus Marine Service Information	0.5° x 0.5°
Sea surface height	E.U. Copernicus Marine Service Information	0.083° x 0.083°

had the lowest Akaike's Information Criteria (AIC) and expressed as:

$$Yi = \alpha + s(SSS) + s(SST) + s(SSHa) + s(current) + s(Chl) + \varepsilon i$$

where Yi is the response variable (catch rate), α is the intercept, f (Xi) is explanatory variable with smoothing function, Xi is categorical variable and εi is the residual or information that is not explained by the model. The optimal degrees or the amount of movement in the smoothing were estimated by cross-validation. Default option in type of a smoother in *mgcv* is a thin plate regression spline but different smoothers according to the data can be used. For example, cyclic cubic regression spline (cc) is a useful smoother since it ensures that the value of the smoother at the far-left point of the gradient is the same as at the far right point of the gradient. Hence, it is a useful smoother for time variable. The plots of the best-fitting smooths for the effect of the covariates were presented as the GAM model results. Relative importance of each covariate of the model was shown in y-axis. Model validations were made on the basis of numerical results and visual inspection of graphs

Results

Fishery

The distribution and abundance of *I. platypterus* along the Arabian Sea was investigated by analysing the data collected from the commercial fishing vessels registered in Tamil Nadu and Kerala. Five species of billfishes were observed in fishery landings namely, *Istiophorus platypterus* (Indo-Pacific sail fish), *Tetrapturus audax* (striped marlin), *Istiompax indica* (black marlin), *Makaira nigricans* (blue marlin) and *Xiphias gladius* (swordfish). Billfishes are common to the Indian coast and the landings have registered a positive trend during the last decade (Fig. 2). The All India landings of *I. platypterus* from 2013-2019 is illustrated in Fig. 3. *I. platypterus* was the most common billfish landed along both the coasts of India. The total landings of billfishes in the country during 2018 was estimated at 16382 t and *I. platypterus* formed 60% (9,929 t) of the billfish catch. Landings of billfish along the maritime states of India and Union territories and the percentage contribution of *I. platypterus* to the total billfishes landing during 2018 is shown in Fig. 4. Species of billfish landed during 2018 by the maritime states along the Indian coast is shown in Fig. 5 and the area of operation is shown in Fig. 1.

Billfishes are generally exploited by multiday gillnetter cum longliners. These crafts are generally manned by fishers from Thoothoor and Kanyakumari region. Details of fishery and fishing operation were collected from the crew of such crafts. The mechanised fishing vessels targeting billfishes had a LOA ranging from 58 to 60 feet, with engine capacity of 300-600 hp. These vessels are manned with a crew of 3-14 members and each fishing trip ranged from 26-32 days. They switch to varied gears, depending on the availability of different fishes. Discussion with the crew revealed that longline was preferred to catch billfish and an average of 13 billfishes

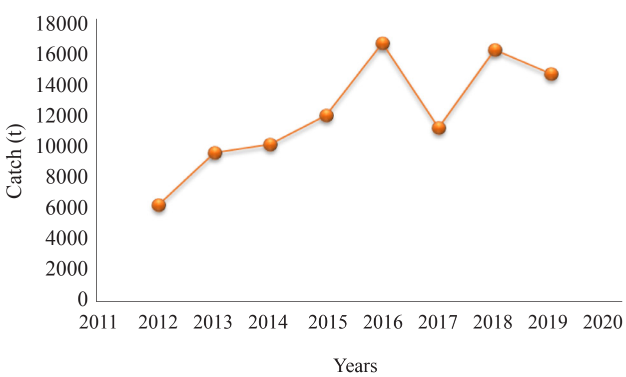

Fig. 2. All India billfish landings 2012-2019

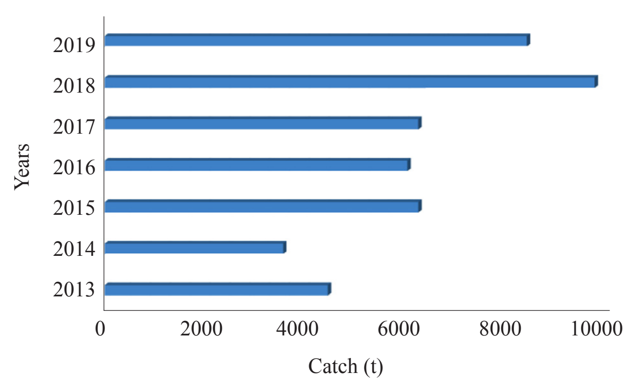

Fig. 3. All India *I. platypterus* landings 2012-2019

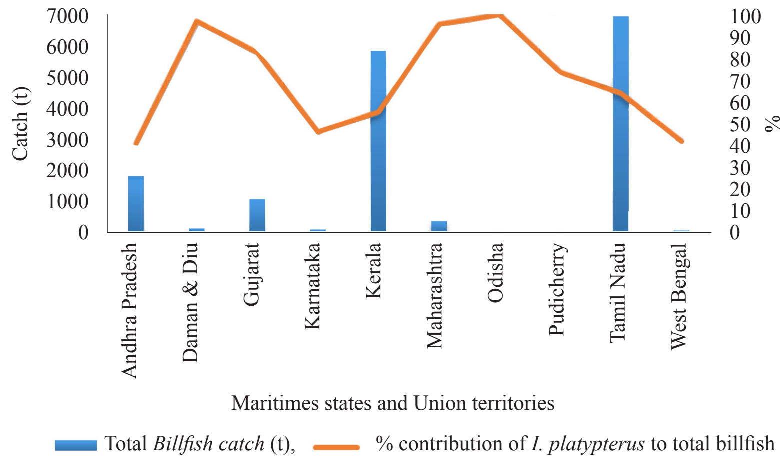

Fig. 4. Billfishes landing along the maritime states of India, including Union territories and the percentage contribution of *I. platypterus* to the total billfish landings during 2018

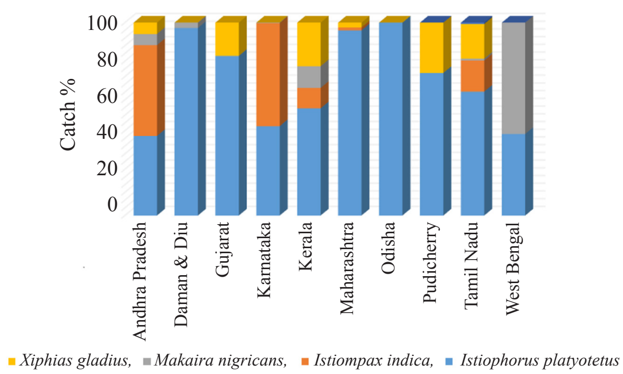

Fig. 5. Percentage landings of different billfish species along the maritime states and Union territories of India

are hooked in a single operation of a longliner as compared to operation of gillnet to catch tunas. These combination vessels therefore operated the lines or gillnets based on the type of fish available in the area. Usually the lines are set in the morning (05.00 hrs and hauled after a duration of 7 h at12:00 hrs . The longlines were set at a distance of 5.5-7.5 km at a depth of 900-1300 m. Each long line unit (called 'basket') consists of the mainline, branch lines, floats and baited hook. The mainlines and branch lines are made of monofilament twine, which are suspended at predetermined depths and kept afloat by means of floats or buoys. The hook type used in operation depends on the target species, its behaviour and size to be captured. Hook (barbed) nos. 4, 5 and 6 were used when billfishes were targeted. A special requirement for line fishing performed to capture billfishes by the Thoothoor fishers is the use of live fish as baits. The most popular and preferred live fish that is used as bait is *Selar crumenophthalmus.* A separate line fishery exists for baitfish. Smaller hooks (no. 14) were used to capture the baits and the captured fishes are kept alive onboard the gillnetters. These live fishes are manually fixed to the hooks and these lines are deployed to capture billfishes.

Spatio-temporal distribution and environmental preferences of I. platypterus

The spatio-temporal distribution maps of *I. platypterus* with catch data was processed in GIS software. The map depicted that the catches were distributed throughout the coast but concentrated mostly in the north-eastern and south-eastern Arabian Sea (Fig. 6). The billfish catch was dominated by *I. platypterus* throughout the study period. The response plots for environmental parameters on the density distribution of *I. platypterus* along the Arabian Sea derived from the GAM are shown in Fig. 7. The spatial distribution of SSS, SST, SSHa, CS and Chl along the Arabian Sea during 2018 is depicted in Fig. 8. The inference analysis for fitting in GAM model was similar to regression model mainly the Chi Square test. The Chi Square test was used to estimate the level of significance for added predictor set at 95% (Table 2). The best fit model for *I. platypterus* was selected on the basis of deviance level **(**32.8%) (Table 3).

The spline of GAM plot showed significant relationship between the catch of *I. platypterus* and the predictor variables. GAM plot showed that salinity varied between 32 and 37 ppt. GAM smoother for the partial effect of SSS on catch (Fig. 7a) showed that there was a positive effect on catch between 32-34 ppt. SST measured over the location where *I. platypterus* is distributed varied between 25 and 31°C. GAM smoother for the partial effect of SST on catch rate (Fig. 7 b) showed a positive effect from 25 to 28°C and SST higher than 28°C had negative effect on catch rate. The GAM smoothing curve showing the partial effect of SSHa on catch rate showed that the

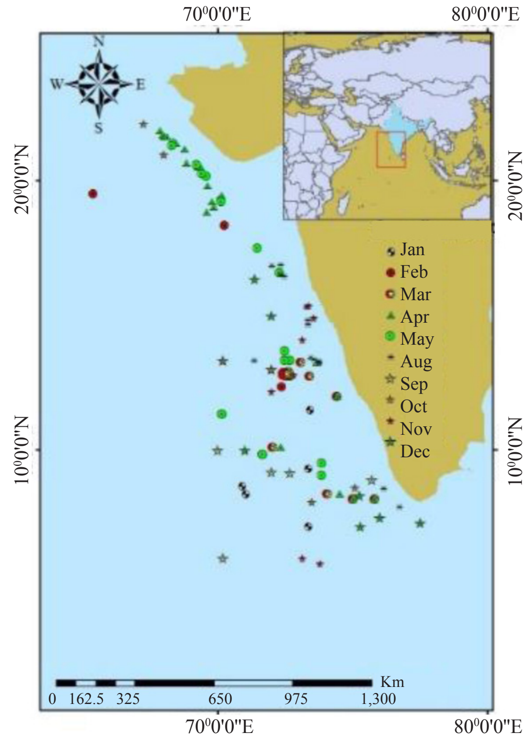

Fig. 6. Spatio-temporal distribution map of *I. platypterus*

Table 2. Summary of parameter estimates applied to explanatory variables

Parameter	df	F	p-value
s(SSS)	2	1.870	p>0.1
s(SST)	2	8.596	p<0.01
s(SSH)	2	5.834	p<0.01
s(CS)	1	21.262	p<0.001
s(Chl)	2	4.698	p<0.05

highest catch value was >0.4 m. Partial effect of SSHa on catch is negative below 0.4 m (Fig. 7c). At lower SSHa values, the effect turned into negative. The spline plot of current speed indicated that it had negative effect on catch rate when current speed was higher than 0.4 m s^{-1} (Fig. 7d). *I. platypterus* was distributed in areas where Chl-a varied between 0.04-2.14 mg m^{-3} (Fig. 7e). Except SSS, all explanatory variables (SST, SSHa, CS, Chl-a) were found to be highly significant covariates ($p<0.01$, $p<0.01$, $p<0.001$ and $p<0.05$ respectively) and in the statistical modelling of catch rate, 38.2% of variance was explained by the model with these variables.

Discussion

This study shows that abundance of *I. platypterus* in north-eastern and south-eastern Arabian Sea was high and comparable to the abundance of *I. platypterus* reported earlier by Ramachandran and Ramalingam (2019) for the west coast of India (FAO area 51). During 2018, an estimated 16382 t of billfishes were landed along the Indian coast (CMFRI, 2019) and the contribution of *I. platypterus* was 9929 t forming 60% of the total billfish landings. *I. platypterus* was the most common billfish landed along both the coasts. Ramachandran and Ramalingam (2019) opined that *I. platypterus* contributed 49 and 57% to the total billfish landings along west coast and east coast respectively and the lat.12-17°N/ long. 69-74°E was moderately productive. The landings of billfishes in the FAO Area 51 has always been greater than FAO Area 57 and the major contributing species was *I. platypterus* (Ganga *et al.,* 2008). This is comparable to the present observation and during 2018 also, *I. platypterus* was the major contributor. The intensity and abundance of *I. platypterus* was observed to be high during March, April

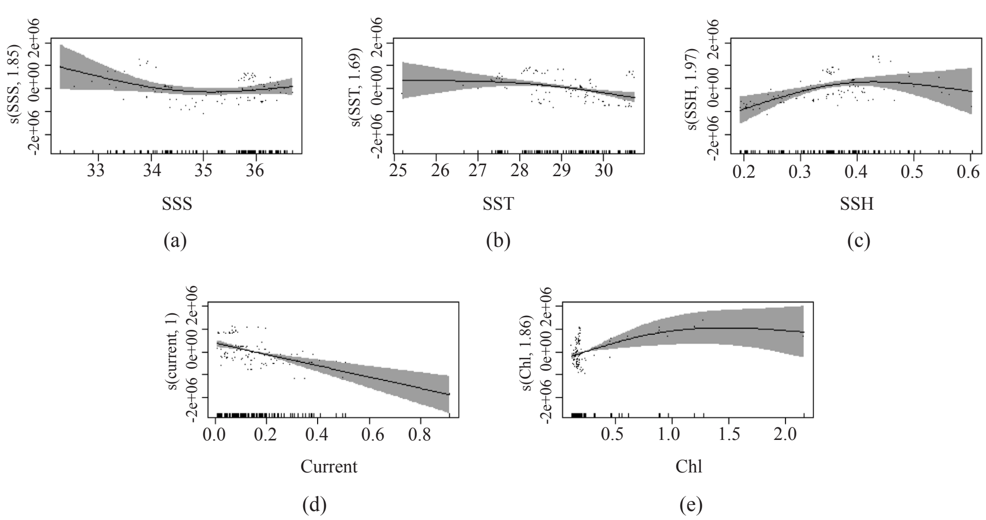

Fig. 7. Response plots for environmental parameters (a) SSS, (b) SST, (c) SSH, (d) CS and (e) Chl, on the density distribution of *I. platypterus* along the Arabian Sea

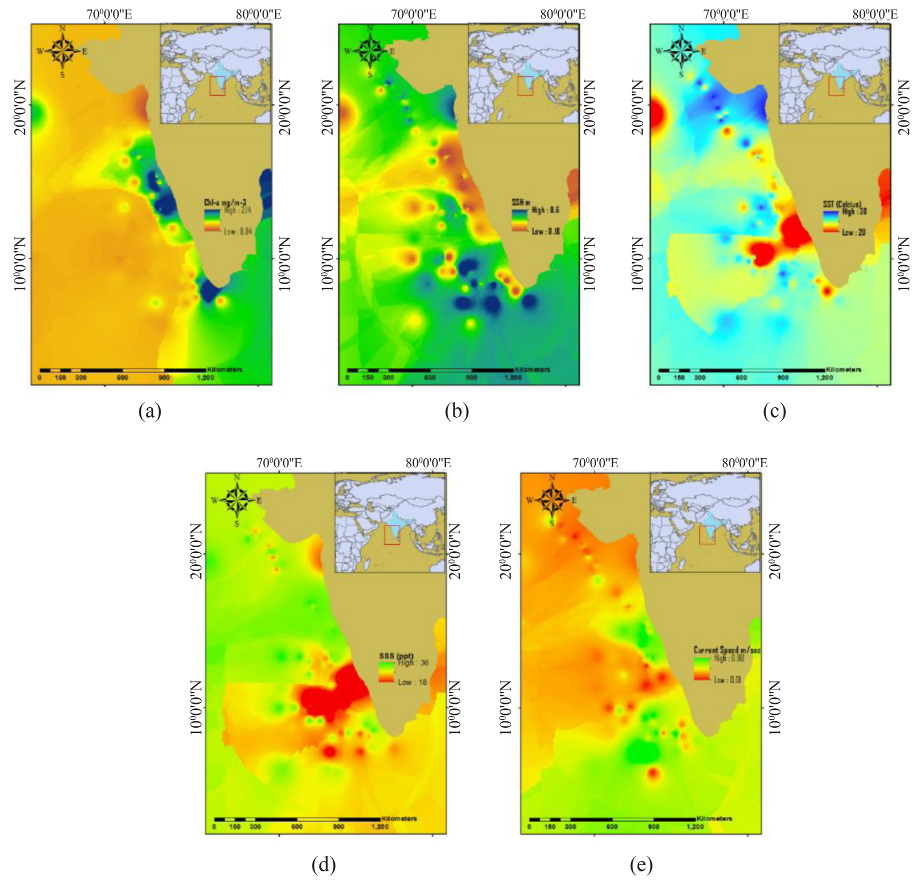

Fig. 8. Spatial distribution of (a) Chl-a, (b) SSH, (c) SST, (d) SSS and (e) CS within Arabian Sea during 2018

Table 3. Analysis of deviance for GAM covariates and their interactions of the best GAM fitted

Parameter	R-sq.(adj)	GCV	Deviance explained %	AIC
s(SSS)	0.0211	3.2768e+11	3.11%	3583
s(SSS)+ s(SST)	0.0361	3.2634e+11	5.66%	3582
s(SSS)+ s(SST)+s(SSH)	0.125	2.9968e+11	15.3%	3572
s(SSS)+ s(SST)+s(SSH)+ s(CS)	0.232	2.6455e+11	26.1%	3556
s(SSS)+ s(SST)+s(SSH)+ s(CS)+s(Chl)	0.278	2.4947e+11	32.8%	3490
Total variation % explained		32.8%		

and December and fishing was concentrated more off Maharashtra, off Gujarat and around Lakshadweep islands during these peak landing months. The fish productivity and abundance are influenced by oceanographic factors and the frequency of fishing trips to the region indicated that fishes tend to concentrate in the specific areas to suit the habitat (Panikkar and Jayaraman, 1966; Rajagopalan *et al.,* 1992; Venu and Kurup, 2002; Satya and Ramesh, 2007). During 2018, Tamil Nadu contributed the maximum (6957 t) billfish landings of the country followed by Kerala (5855 t). The site selection and the participation of Thoothoor fishers from Kanyakumari District (Tamil Nadu) clearly depicted their active role in the exploitation of sharks and large pelagics from the entire west coast of India. This group of fishers, travel all along the coast of India and venture into deep waters between 7° to 23°N and 60° to 74°E. These fishermen have a long history of performing targeted fishery for sharks and undertake month-long risky voyages into international waters in search of sharks (Fernando *et al.,* 2017). Shinoj *et al.* (2020) reported that the Thoothoor fishers are the most skilled multiday offshore fishermen operating hundreds of fishing vessels and contributed 70% of the offshore resources harvested. They target offshore resources, the most common being tunas, sharks, rays, seer fishes and billfishes (Shinoj *et al.,* 2020).

The abundance of billfishes and their relationship with the oceanographic parameters in the Arabian Sea has hardly been reported except for the resource dynamics study in the eastern Arabian Sea (Ganga *et al*., 2012). Studies made so far include reports from the Bay of Bengal by Rathnasuriya *et al.* (2016) and Bandaranayake *et al*. (2018).

GAM response plot for Chl-a indicated that the preferred areas had low values. Being a top predator of the trophic niche, *I. platypterus* is seen in areas with low primary productivity. Similarly, Mohammed *et al.* (2018) found that the abundance of *Stenotheuthis oualaniensis,* a deep-sea carnivore in the eastern Arabian Sea was negatively related to chlorophyll content. Rathnasuriya *et al.* (2016) also found that the swordfish abundance in the Bay of Bengal was associated with low sea surface chlorophyll values. Fishermen while collecting data informed that, the billfishes were normally associated with the deeper layers, so being an inhabitant of the deep ocean almost below the euphotic zone, the fishes were adapted to areas with low chlorophyll content and their abundance therefore was in low Chl-a regions of the ocean. The curve fit to the modelled distribution found that the highest abundance of *I. platypterus* was recorded at SST of 29°C and the positive effects in the catch were observed at SST ranging from 25 to 31°C. SST values showed positive relationship with *I. platypterus* abundance which was similar to the findings by other researchers (Muto *et al*., 2000; Ramteke *et al.,* 2020). Block *et al*. (1992a) used multiplex acoustic transmitters to monitor swimming speed, preferred water temperature and body temperature of blue marlins off the Kona coast of Hawaii and found that the fishes mostly remained in the top 200 m. Their preferred zone was up to 10 m and they rarely ventured below the thermocline. The uniformly warm near surface water temperature (25 to 27°C) was the preferred zone and excursions below 10 m were usually less than 60 min duration (Block *et al*., 1992b). The fishable area of *I. platypterus* relevant to SSS varied from 32-37 ppt and SSS values up to 36 ppt had a positive effect on the expected abundance. Rooker *et al.* (2012) found that the density of sailfish was typically greater at higher salinities (36 ppt). Salinity has been reported to be one of the crucial factors determining species availability and spatio-temporal distribution (Weinstein *et al.,* 1980; Marshall and Elliott, 1998). Nima *et al*. (2018) also studied the habitat preference of marlins along the eastern Pacific ocean and indicated that the eco-suitability for marlins was in areas where salinity was >35 ppt. The presence of *I. platypterus* increased as current speed increased up to velocities of 0.4 m s^{-1} where the fishes were seen with a current speed of 0.01 to 0.9 m s^{-1}. Billfishes are the fastest swimmers in the ocean (Svendsen *et al.,* 2016) and preferred lesser current speed (0.1-0.4 m s^{-1}). Rooker *et al.* (2012) also predicted negative relationship between current speed and sailfish abundance. The present model predicted that the probability of high catch for *I. platypterus* was when SSHa was 0.2- 0.4 m, though the fish was seen throughout the range from 0.18 to 0.6 m. SSHa anomaly controls the water movement and is used to delineate mesoscale eddies. It often signifies upwelling and results in a flux of cool nutrient rich waters. Rooker *et al*. (2012) also observed higher densities of sailfish with negative sea surface height anomalies.

Physical oceanographic features determine the marine community structure and influence the density and abundance of each trophic level species. Both fishery independent and dependent data form valuable inputs for the assessment of spatio-temporal distribution of fishes. The findings of the present study are based on commercial fish landings data to estimate fish catch and remotely sensed oceanographic parameters from the Arabian Sea to predict the eco-suitability and habitat preference of *I. platypterus.* The use of GAM analysis to predict the relationship of different parameters with the catch of *I. platypterus* showed that, the variables are influential on the spatio-temporal distribution and abundance of fish in the Arabian Sea. Space time factor plays a significant role in predicting the eco-suitability and variance in the catch of *I. platypterus*, and it can be concluded that the SST, SSHa and CS together with catch are important parameters in predicting the habitat preference of the fish. The capability of high temporal resolution satellite remote sensing to provide the required oceanic data can therefore be used as a better indicator to predict the abundance/ catch per unit effort (CPUE) of *I. platypterus*.

Acknowledgements

The authors are thankful to Dr. A. Gopalakrishnan, Director ICAR-CMFRI, Kochi and Dr. Gopal Krishna, Director, ICAR-CIFE, Mumbai for their constant support and funding. The first author thanks all the staff members of Vizhinjam Regional Centre of ICAR-CMFRI and fishers of Kanyakumari District, Tamil Nadu for their kind cooperation and support.

References

Al-Kharusi, L. H. 2008. Predicting the distribution and abundance of emperor fishes (*Lethrinus* spp.) in the Arabian Sea using two-stage generalised additive models and a geographic information system. *J. Agric. Mar. Sci.*, 13: 7-22. doi:10.24200/jams.vol13iss0pp7-22.

Azeez, A. P. A., Mini, R., Prathibha, R., Latha, S., Ashok, K. J., Mohammed, K. and Divu, D. 2021. Predicting potential fishing grounds of ribbonfish (*Trichiurus lepturus*) in the north-eastern Arabian Sea, using remote sensing data. *Int. J. Remote Sens.,* 42(1): 322-342. DOI: 10.1080/01431161.2020.1809025.

Bandaranayake, K. H. K., Gunasekhara, S. S., Weerasekera, S. J., Jayathilaka, R. M. and Haputhantri, S. S. K. 2018. *Monsoon and temperature effects on swordfish (Xiphias gladius) catches in the high seas of Indian Ocean: A case study in high seas longline fishery of Sri Lanka.* IOTC Sixteenth Working Party on Bill Fish, Cape Town, South Africa.

Bellido, J. M., Pierce, G. J. and Wang, J. 2001. Modelling intra-annual variation in abundance of squid *Loligo forbesi* in Scottish waters using generalised additive models. *Fish. Res.*, 52: 23-39.

Bishnupada, S. and Ansy Mathew, N. P. 2014. Review of billfish biology from Indian fishery. *IOTC–2014–WPB12–11 Rev_2*.

Block, B. A., David, B. and Francis, G. C. 1992a. Direct measurement of swimming speeds and depth of blue marlin. *J. Exp. Biol*., 166: 267-284.

Block, B., Booth, D. and Carey, F. 1992b. Depth and temperature of the blue marlin, *Makaira nigricans*, observed by acoustic telemetry. *Mar. Biol.,* 114: 175-183.

Botsford, L. W., Castilla, J. C. and Peterson, C. H. 1997. The management of fisheries and marine ecosystems. *Science*, 277(5325): 509-515. DOI: 10.1126/science.277.5325.509.

Brodie, S., Hobday, A. J., Smith, J. A., Everett, J. D., Taylor, M. D., Gray, C. A. and Suthers, I. M. 2015. Modelling the oceanic habitats of two pelagic species using recreational fisheries data. *Fish. Oceanogr.,* 24(5): 463-477. doi:10.1111/fog.12122.

Bruno, L. M., Felipe, C., Michael, M., Alberto, A., Jose, C. P., Humberto, H. and Fabio, H. 2014. Short-term movements and habitat preferences of sailfish*, Istiophorus platypterus* (Istiophoridae) along the southeast coast of Brazil. *Neotrop. Ichthyol.,* 12(4): 861-870.

Bruno, L. M., Mariela, N., Alberto, F., Amorim De, Humberto, H., Felipe, C., Fabio, H. and Freddy, A. 2018. Reproductive biology and space–time modelling of spawning for sailfish *Istiophorus platypterus* in the western Atlantic Ocean. *Mar. Biol. Res.*, 14: 269-286.

Chang, Y., Sun, C., Chen, Y., Yeh, S. and Dinardo, G. 2012. Habitat suitability analysis and identification of potential fishing grounds for swordfish *Xiphias gladius*, in the South Atlantic Ocean. *Int. J. Remote Sens*., 33(23): 7523-7541. doi:10.1080/ 01431161.2012.685980.

Chen, X., Li, G., Feng, B. and Tian, S. 2009. Habitat suitability index of chub mackerel *(Scomber japonicus*) from July to September in the East China Sea. *J. Oceanogr*., 65: 93-102. doi:10.1007/s10872-009-0009-9.

Chiang, W. C., Musyl, M. K., Sun, C. L., DiNardo, G., Hung, H. M., Lin, H. C., Chen, S. C., Yeh, S. Z., Chen, W. Y. and Kuo, C. L. 2015. Seasonal movements and diving behaviour of black marlin (*Istiompax indica*) in the North-western Pacific Ocean. *Fish. Res*., 166: 92-102. https://doi.org/10.1016/j.fishres.2014.10.023.

CMFRI 2019. *CMFRI Annual Report 2018-19*. ICAR-Central Marine Fisheries Research Institute, Kochi, India. http://eprints.cmfri.org.in/id/14753.

Collette, B. B., McDowell, J. R. and Graves, J. E. 2006. Phylogeny of recent billfishes (Xiphioidei). *Bull. Mar. Sci.,* 79(3): 455-468.

Cury, P. M., Mullon, C., Garcia, S. M. and Shannon, L. J. 2004. Viability theory for an ecosystem approach to fisheries. *ICES J. Mar. Sci.*, 62: 577-584. https://doi.org/10.1016/j.icesjms.2004.10.007.

Dineshbabu, A. P., Thomas, S. and Dinesh, A. C. 2016. Handbook on application of GIS as a decision support tool in marine fisheries. *CMFRI Special Publication No. 121,* ICAR-Central Marine Fisheries Research Institute, Kochi, India.

Drexler, M. and Ainsworth, C. H. 2013. Generalized additive models used to predict species abundance in the Gulf of Mexico: An ecosystem modeling tool. *PLoS ONE,* 8(5): e64458. doi:10.1371/*journal.pone*.0064458.

Emmanuel, C., Sylvain, B., Gabriel, R., Karen, N., Jeffrey, J. P., Martin, H. and Nicholas, K. 2011. Satellite remote sensing for an ecosystem approach to fisheries management. *ICES J. Mar. Sci.*, 68(4): 651-666. https://doi.org/10.1093/icesjms/fsq195.

Fernando, H., Ananthan, P. S. and Daniel, N. 2017. Shark fishing - A unique traditional fishing practice in Thoothoor, Tamil Nadu, India. *Ecol. Environ. Conserv.*, 23: S10-S15.

Ganga, U., Pillai, N. G. K. and Elayathu, M. N. 2008. Billfish fishery along the Indian coast with special reference to the Indo-Pacific sailfish *Istiophorus platypterus* (Shaw and Nodder 1792). *J. Mar. Biol. Ass. India,* 50(2): 166-171.

Ganga, U., Elayathu, M. N., Prakasan, D., Rajoolshanis, C. P., Akhilesh, K. V. and Retheesh, T. B. 2012. Resource dynamics of the Indo-Pacific sailfish *Istiophorus platypterus* (Shaw, 1792) from the south-eastern Arabian Sea. *Indian J. Fish.,* 59(3): 61-64.

Garcia, S. M. and Cochrane, K. L. 2005. Ecosystem approach to fisheries: A review of implementation guidelines. *ICES J. Mar. Sci.*., 62: 311-318. https://doi.org/10.1016/j.icesjms.2004.12.003.

Genoveva, C., Enrique, M. B., Maria, C. R., Augustin, H. H. and Andres, A. 2013. Seasonal reproduction of sailfish *Istiophorus platypterus* from the southeast Mexican Pacific. *Mar. Biol. Res.,* 9(4): 407-420. DOI:10.1080/17451000.2012.742545.

Hastie, T. J. and Tibshirani, R. J. 2017. *Generalised additive models*, 1st edn. Chapman and Hall/CRC, Routledge, Taylor and Francis Group, UK.

ITIS 2008. *Istiophoridae ITIS Taxonomic Serial No. 172486*. Integrated Taxonomic Information System (Accessed 27 December 2008).

Lan, K. W., Shimada, T., Lee, M. A., Su, N. J. and Chang, Y. 2017. Using remote-sensing environmental and fishery data to map potential yellow fin tuna habitats in the tropical Pacific Ocean. *Remote Sens.,* 9: 444. doi:10.3390/rs9050444.

Lee, D., Son, S. H., Kim, W., Park, J. M., Joo, H. and Lee, S. H. 2018. Spatio-temporal variability of the habitat suitability index for chub mackerel (*Scomber japonicus*) in the East/Japan Sea and the South Sea of South Korea. *Remote Sens.,* 10: 938. doi:10.3390/rs10060938.

Madhupratap, M. S., Prasannakumar, P. M., Dileepkumar, B. M., Raghukumar, S., Nair, K. K. C. and Ramaiah, N. 1996. Mechanisms of the biological response to winter cooling in the North Eastern Arabian Sea. *Nature,* 384: 549-552. doi:10.1038/384549a0.

Marshall, S. and Elliott, M. 1998. Environmental influences on the fish assemblage of the Humber Estuary, UK, *Estuar. Coast. Shelf. Sci.,* 46: 175-184.

Mohammed, S. K., Sajikumar, K., Ragesh, N., Ambrose, T. V., Jayasankar, J., Said Koya and Geetha, S. K. 2018. Relating abundance of purpleback flying squid *Sthenoteuthis oualaniensis* (Cephalopoda: Ommastrephidae) to environmental parameters using GIS and GAM in South-Eastern Arabian Sea. *J. Nat. Hist.,* 52(29-30): 1869-1882. https://doi.org/10.1080/00222933.2018.1497721.

Mumby, P. J., Skirving, W., Strong, A. E., Hardy, J. T., LeDrew, E. F., Hochberg, E. J., Stumpf, R. P. and David, L. T. 2004. Remote sensing of coral reefs and their physical environment. *Mar. Pollut. Bull*., 48(3-4): 219-228.

Muto, E. Y., Soares, L. S. H. and RossI-Wongtschowski, C. L. D. B. 2000. Demersal fish assemblages of Sao Sebastiao, South Eastern Brazil: Structure and environmental conditioning factors (summer 1994). *Rev. Bras. Oceanogr.,* 48(1): 9-20. https://doi.org/10.1590/S1679-87592000000100002.

Nakamura, I. 1985. FAO species catalogue, vol. 5. Billfishes of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. *FAO Fish. Synop.*, *125*. Food and Agriculture Organisation of the United Nations, Rome, Italy.

Nelson, J. S. 2006. *Fishes of the world,* 4th edn. John Wiley and Sons, Hoboken, New Jersey, USA.

Nima, F. H., Michael, G., Thompson, A. R. and Yin, Z. 2018. Habitat preferences of blue marlin *(Makaira nigricans)* and black marlin *(Istiompax indica)* in the Eastern Pacific Ocean. *University of San Diego Thesis*, 32. https://digital.sandiego.edu/theses/32.

Palacios-Abrantes, J., Reygondeau, G., Wabnitz, C. C. and Cheung, W. W. 2020. The transboundary nature of the world's exploited marine species. *Sci. Rep.,* 10(1): 1-12. DOI:10.1038/s41598-020-74644-2.

Panikkar, N. K. and Jayaraman, R. 1966. Biological and oceanographic differences between the Arabian Sea and the Bay of Bengal as observed from the Indian region. *Proc. Indian Acad. Sci. B.*, 64(5): 231-240.

Partrizia, P., Pietro, B., Pierpaolo, C., Franco, A. and Teresa, R. 2016. Swordfish monitoring by a GIS based spatial and temporal distribution analysis on harpoon fishery data: A case of study in the central Mediterranean Sea. *Fish. Res.,* 183: 424-434. DOI:10.1016/j.fishres.2016.07.006.

Rajagopalan, M. S., Thomas, P. A., Mathew, K. J., Selvaraj, G. S. D., George, R. M., Mathew, C. V., Naomi, T. S., Kaladharan, P., Balachandran, V. K. and Antony, G. 1992. Productivity of the Arabian Sea along the southwest coast of India*. CMFRI Bulletin No. 45*, ICAR-Central Marine Fisheries Research Institute, Kochi, India, p. 9-37.

Ramachandran, S. and Ramalingam, L. 2019. Distribution, abundance and some biological aspects of bill fish species under the family Xiphiidae (*Xiphias gladius*) and Istiophoridae (*Istiophorus platypterus*, *Istiompax indica, Makaira nigricans*) in Indian EEZ. *IOTC-2019-WPB: 17-26.*

Ramteke, K. K., Shenoy, L., Nayak, B. B., Deshmukhe, G., Inamdar, A. B. and Singh, V. V. 2020. Assessing the impact of environmental factors influencing the spatio-temporal distribution of *Johnius belangerii* (Cuvier, 1830) Belanger's croaker along Mumbai, North-west coast of India. *Indian J. Geo-Mar. Sci*., 49(05): 903-907.

Rathnasuriya, M. I. G., Gunasekara, S. S., Haputhanthri, S. S. K. and Rajapaksha, J. K. 2016. Environmental preferences of billfish in Bay of Bengal: A case study in longline fishery of Sri Lanka, *IOTC.WPB 14-2016-10 Rev1*.

Romeo, T., Perzia, P., Esposito, V., Malara, D., Battaglia, P., Consoli, P., Canese, S. and Andaloro, F. 2011. Relationship between swordfish swimming behaviour and sea surface temperature in the central Mediterranean Sea during the reproductive period. *Mar. Biol. Res*., 7: 186-194. https://doi.org/10.1080/17451000.2010.489615.

Romeo, T., Battaglia, P., Raicevich, S., Perzia, P. and Andaloro, F. 2015. Swordfish harpoon fishery in the Mediterranean Sea: Recent data to implement the Marine Strategy Framework Directive and the EcAp (Ecosystem Approach) process. *Fish. Res.,* 161: 191-199. DOI:10.1016/j.fishres.2014.07.013.

Rooker, J. R., Simms, J. R., Wells, R. J. D., Holt, S. A., Holt, G. J. and Graves, J. E. 2012. Distribution and habitat associations of billfish and swordfish larvae across mesoscale features in the Gulf of Mexico. *PloS ONE,* 7(4). e34180. https://doi.org/10.1371/journal.pone.0034180.

Satya, P. and Ramesh, R. 2007. Is the Arabian Sea getting more productive? *Curr. Sci*., 92(5).

Shinoj, P., Ramachandran, C., Muktha, M., Baiju, K. K., Prathibha, R., Narayanakumar, R., Shelton, P. and Shiv Kumar. 2020. Harnessing artisanal powers in offshore fisheries: The case of Thoothoor fishers from India. *Mar. Policy,* 121: 1-8.

Solanki, H. U., Bhatpuria, D. and Chauhan P. 2016. Applications of Generalized Additive Model (GAM) to satellite-derived variables and fishery data for prediction of fishery resources distributions in the Arabian Sea. *Geocarto Int*., 32: 30-43. doi:10.1080/ 10106049.2015.1120357.

Somvanshi, V. S. and Varghese, S. 2001. Distribution, abundance indices and some biological characteristics of the Indo-pacific sail fish *Istiophorous platypterus* (Shaw and Nodder, 1792) in the North Western Indian EEZ. *IOTC,* 4: 164-168.

Srinath, M., Somy, K. and Mini, K. G. 2005. Methodology for the estimation of marine fish landings in India. *CMFRI Special Publication No. 86*, ICAR-Central Marine Fisheries Research Institute, Kochi, India.

Staples, D., Brainard, R., Capezzuoli, S., Funge-Smith, S., Grose, C., Heenan, A., Hermes, R., Maurin, P., Moews, M., O'Brien, C. and Pomeroy, R. 2014. Essential EAFM. *Ecosystem Approach to Fisheries Management Training Course, Vol. 1 - For Trainees. RAP Publication 2014/13*, 318 pp.

Su, N. J., Sun, C. L., Punt, A. E., Yeh, S. Z. and DiNardo, G. 2011. Modelling the impacts of environmental variation on the distribution of blue marlin, *Makaira nigricans* in the Pacific Ocean. *ICES J. Mar. Sci.,* 68: 1072-1080.

Svendsen, M. B., Domenici, P., Marras, S., Krause, J., Boswell, K. M., Rodriguez-Pinto, I., Wilson, A. D., Kurvers, R. H., Viblanc, P. E., Finger, J. S. and Steffensen, J. F. 2016. Maximum swimming speeds of sailfish and three other large marine predatory fish species based on muscle contraction time and stride length: A myth revisited. *Biol. Open.*, 5(10): 1415-1419.

Turner, W., Spector, S., Edward, P. G., Mathew, F. and Eleanor, S. 2003. Remote sensing of biodiversity and conservation. *Trends Ecol. Evol*., 18(6): 306-314.

Valvanis, V. D. 2008. Essential habitat mapping in the Mediterranean. *Hydrobiologia,* 612: 5-20. DOI:10.1007/ s10750-008-9493-y.

Varghese, S., Somvanshi, V. and Deepak, K. G. 2013. Ontogenetic and seasonal variations in the feeding ecology of Indo-pacific sailfish, *Istiophorous platypterus* (Shaw, 1792) of the eastern Arabian Sea. *Indian J. Geo-Mar. Sci.,* 42(5): 593-605.

Venu, S. and Kurup, B. M. 2002. Distribution and abundance of deep sea fishes along the west coast of India. *Fishery Technol.,* 39(1): 20-26.

Weinstein, M. P., Weiss, S. L. and Walters, M. F. 1980. Multiple determinants of community structure in shallow marsh habitats, Cape Fear River Estuary, North Carolina. *Mar. Biol*., 58: 227-243.

Worm, B., Sandow, M., Oschlies, A., Lotze, H. K. and Myers, R. A. 2005. Global patterns of predator diversity in the open oceans. *Science,* 309(5739): 1365-1369. doi: 10.1126/ science.1113399.

Yen, K. W., Lu, H. J., Chang, Y. and Lee, M. A. 2012. Using remote-sensing data to detect habitat suitability for yellowfin tuna in the Western and Central Pacific Ocean. *Int. J. Remote Sens.,* 33(23): 7507-7522. doi:10.1080/0143 1161.2012.685973.

Date of Receipt : 29.03.2021

Date of Acceptance : 05.04.2022