



Characterisation of season-wise spatial distribution of small pelagic fishery in Kerala, south-west coast of India

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ABSTRACT

In this study, we attempted to identify and characterise the spatial variability of small pelagic fish abundance using geo-statistical methods. The small pelagic fish abundance was estimated in terms of spatial parameters using generalised additive models (GAMs). The ring seine fishing grounds in the south-eastern Arabian Sea exhibited seasonal variability in distribution. Results of the study would help in prediction of the major pelagic fishing grounds for traditional fishers which would help in reducing fuel and time spent on searching for the fishing ground leading to sustainable exploitation. The prediction model can contribute to the management of pelagic fishery along the Kerala coast.

Keywords: Generalised additive model, Kerala, Pelagic fisheries, Ring seine, Seasonal variations, Spatial variables

Introduction

The state of Kerala is situated in the west coast of Peninsular India with a coast line of 590 km and ranks fourth in marine fish production in the country, contributing 0.52 million t to the country's marine landings. Pelagic fishery resources play a significant role in Kerala's marine fish production (CMFRI, 2016). This group exhibits rich species diversity and abundance in the Indian EEZ with 240 species and contributes about 52% of the marine landings (Pillai and Ganga, 2008). Small pelagics such as the Indian oilsardine and Indian mackerel together contribute 21% of the catch (CMFRI, 2016). In Kerala, pelagic resources contribute 61% of the total landings and the ring seine fishery is the major contributor with 92.8% of oilsardine and 51% of mackerel landings (CMFRI, 2016). Ring seines are classified under surrounding nets or encircling nets and come under the group of active fishing gear (Nedlec, 1982; Brandt, 1984; Ben-yami, 1994; Edwin and Hridayanathan, 1996; Sainsbury, 1996; Hameed and Boopendranath, 2000). Knowledge of the spatial distribution of fishing grounds and the ability to analyse the variability of species composition in the resulting regions can lead to sustainable management which could help in protecting the marine ecosystem from stress as well as in reducing bycatch (Botsford *et al.*, 1997; Babcock *et al.*, 2005).

Many researchers have attempted the spatial analysis and seasonal variation of fisheries worldwide. Silvano and Begossi (2001) studied the small-scale fishery in the Piracicaba River in south-eastern Brazil, with regards to the diversity, quantity and composition of

fish catches during different seasons. Axenrot and Hansson (2004) quantified pelagic fish abundance in Baltic Sea using hydroacoustics and the variation, expressed with the help of geostatistical coefficient of variation revealed intra-annual dynamics in acoustic fish abundance, densities and size composition. Wilde and Paulson (1989) studied the spatial and temporal patterns in fish abundance in Lake Mead, Arizona-Nevada using nonparametric statistical methods. The spatial and temporal patterns in distribution of cuttlefish abundance and its relationships with environmental variables in the French Atlantic coast was studied by Wang *et al.* (2003) using geographical information system and statistical methods. However studies in this line are limited in India (Hegde *et al.*, 2016).

Application of geo-statistics to study spatial distribution started in 1950s as autocorrelation model and were extensively used for ecological studies in 1970s to 1980s (Berry and Marble, 1968). In 1990s, it became the main statistical method used for spatial application (Deutsch, 2002). Geostatistics application on demersal fishery resources was widely used a few decades ago (Petitgas and Poulard, 1989; Sullivan, 1991; Freire *et al.*, 1992; Simard *et al.*, 1992; Gurriarán *et al.*, 1993; Pelletier and Parma, 1994; Maynou, 1998; Maynou *et al.*, 1998). Petitgas (1993) used geostatistical application for the stock assessment of pelagic fishes. Small pelagic fishes have extensive variations in both their distribution and abundance over time (Kawasaki, 1984; Lluch-Belda *et al.*, 1989) influenced by seasonal, inter-annual and decadal marine climate variations (Lluch-Belda *et al.*, 1989; Bakun and Broad 2003; de Young *et al.*, 2004).

Generalised additive models (GAM) are common statistical tools used for stating the relationship between response and predictor variables with the help of nonparametric and semiparametric techniques (Hastie and Tibshirani, 1990). The south-east Arabian Sea bordering the west coast of India experiences intense rainfall activity during the summer monsoon season, and is also influenced by large cloud cover (Suprit and Shankar, 2008) which adversely affects the satellite aided fishing and fishery forecasting (Ravichandran *et al.*, 2012). In these circumstances, time series catch data aided models will help to predict the fishing zones more accurately.

The primary objective of the present study was to identify and characterise abundance and spatial distribution of small pelagic fish of south-eastern coastal Arabian Sea with respect to different seasons. The secondary objective was to develop an algorithm to predict the major pelagic fishing grounds for traditional fishers to reduce fuel and time spent on searching for fishing grounds.

Materials and methods

The study was carried out in Kerala, which lies along south-eastern Arabian Sea (Fig. 1). Ring seine fishing is said to have been first introduced to the country along this stretch of the coast (Panicker *et al.*, 1985). About 62.5% of the fishers of this area are mainly dependent on the mini purse seine (popularly known as ring seine) fishery for their livelihood (Das *et al.*, 2012).

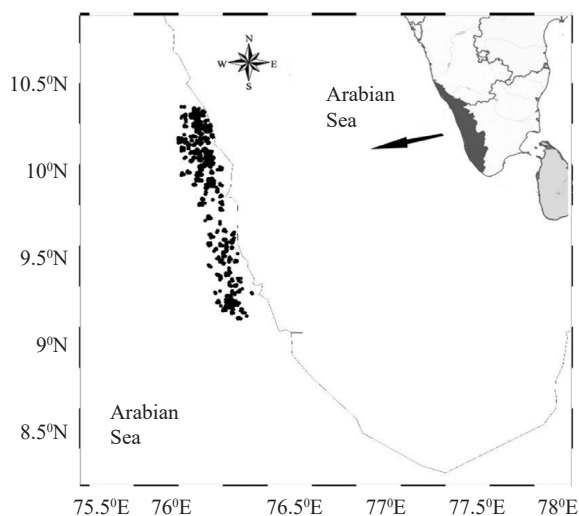


Fig.1. Map of the study area (Kerala) along with fishing locations

The present study was conducted during January 2010 to January 2012. The detailed landing information with reference to species and fishing area [GPS (Global Positioning System) locations] were collected from ring seine vessels operating in this region. The data for 1162

fishing trips of 22 fishing vessels were collected and the GPS data was converted into decimal for easy analysis. GPS data on fishing positions were collected with a Furuno Marine GPS/WAAS Navigator (Model G-32) fixed onboard the fishing vessel. Catch and species-wise information were collected from log books maintained in the vessel. Non-target fishes and the accidental occurrence of high value fishes, which comprises a negligible fraction of the total catch, were excluded from the study. For analytical purpose, months were grouped into seasons: pre-monsoon (February-May), monsoon (June-September) and post-monsoon (October-January) (Sreekanth *et al.*, 2017). The analyses comprise of characterisation and illustration of fish yield (abundance) distribution using geo-statistical analysis and estimation of yield abundance in terms of spatial parameters using statistical modeling techniques.

To identify the spatial distribution of the two dominant pelagic fish species *viz.*, sardine (*Sardinella longiceps*) and mackerel (*Rastrelliger kanagurta*), one way analysis of variance was used to test the effect of season as an independent factor on catch. The average successful fishing days during different seasons were compared using Tukey's HSD (honestly significant difference). The catch per unit effort (CPUE) was estimated as kg day⁻¹ boat⁻¹ (El-Haweet, 2004). The spatial distribution of pelagic fish in relation to the fishing ground was mapped using ODV (Ocean Data View) freeware package for oceanographic visualisation software (Schlitzer, 2011) with respect to latitude and longitude. A two dimensional contour map of fish yield was also drawn to get an idea of variability in the yield.

The spatial dependence/characterisation of fish yield was quantified using a variogram. Standardised semivariogram on season-wise sardine and mackerel catch was computed and plotted for analysing the spatial distribution of fish abundance. Euclidean distance on fish yield of each species during different seasons was computed for each pair of observations at several fishing locations (latitude and longitude). The sample standardised semivariogram at a specific lag-distance 'h' was estimated on all pair of points separated by the distance 'h' and it is given by:

$$\hat{\gamma}(h_k) = \frac{1}{2|N(\theta_k, L)|} \sum_{p_i p_j \in N(\theta_k, L)} [V(s_i) - V(s_j)]^2$$

where h_k in the average distance in class $N(\theta_k, L)$

$$i.e., h_k = \frac{1}{|N(\theta_k, L)|} \sum_{p_i p_j \in N(\theta_k, L)} |p_i p_j|$$

$V(S_i) - V(S_j)$ are the difference between the spatial variance of locations s_i and s_j ; $(P_i P_j)$ is $(i, j)^{th}$ pair of observation.

Then, from each sampling point S_i , the distance to each location was computed and arranged according to the specified distance classes. The squared difference of density values for each pair of samples pertaining to a given lag was then computed. Finally the estimated variogram value for a given lag was obtained by dividing the sum of squared differences by the number of pairs of sampling points pertaining to this lag. The semivariogram estimates were used to illustrate the spatial data as a function of correlation structure of dependent variable (fish yield) and the location parameters (latitude and longitude) (Matheron, 1963; Schabenberger and Gotway, 2005).

The next step was to develop the algorithm for predicting spatial occurrence. The statistical modeling techniques of spatial data considered here are an extension of regression analyses when linearity is not assumed and multiple penalised regression splines are used and these models are known as generalised additive models (GAM) (Hastie and Tibshirani, 1990; Wood, 2004). GAM with usual regression parameters and smoothing parameters for latitude and longitude was used to estimate the fish abundance with respect to location parameters and it was done separately for sardine and mackerel catch. GAM function of additive explanatory variable was used to establish a relationship between the mean of the response variable and a 'smoothed' function of the explanatory variable(s) (Hastie and Tibshirani, 1986):

$$Y_i = \beta_0 + \beta_1(X_1) + \beta_2(X_2) + S_1(X_1) + S_2(X_2) + \epsilon_i$$

where, Y_i = Fish yield; X_1 = Latitude; X_2 = Longitude; $\beta_1 + \beta_2$ are linear regression coefficient; S_1 = Smoothing function of latitude; S_2 = Smoothing function of longitude; ϵ_i = Error term

The regression parameters were estimated by ordinary least square method and the smoothing parameters were estimated using Backfitting algorithm. All the statistical analyses were carried out using Proc variogram and Proc JAM in Statistical Analysis System software SAS 9.3. (SAS, 2012).

Results and discussion

Abundance and spatial distribution

The total successful fishing days during the period of study in pre-monsoon, monsoon and post-monsoon seasons were 184, 230 and 165 days respectively and CPUE was 3335.21 ± 1836.19 kg day⁻¹,

5799.36 ± 2159.33 kg day⁻¹ and 3366.97 ± 2104.59 kg day⁻¹ respectively. Das *et al.* (2012) observed large number of ring seine operations in the same region during monsoon season. Boopendranath and Hameed (2012) reported that monsoon period showed high landings in ring seines.

The contour plot of sardine and mackerel yield during different seasons is depicted in Fig. 2 and it was noticed that the data expressed spatial variability in the fish yield for both sardine and mackerel. The fish yield data showed numerous scattered patterns in all seasons because of the catch variability in the purse seine fishery in different seasons. Sardine and mackerel showed a variability of 1.0-12.0 and 1.0-14.0 t respectively.

The pelagic fish distribution showed spatial variation over the three seasons *viz.*, pre-monsoon, monsoon and post-monsoon. The fish distribution varied between 9.050-10.355° N to 76.00-76.415° E and the spatial distribution variability of sardine and mackerel abundance is depicted in Fig. 3. no significant difference was observed between the variability of sardine and mackerel yield during different seasons. But the fish distribution exhibited a significant difference ($p < 0.05$) of seasonal shift of fishing ground which also indicated a clear sign of spatial displacement. During monsoon season, fishing ground shifted below 9.5° N, exhibiting a southward shift of fishing ground during the period.

The spatial dependence of sardine and mackerel yield abundance was also computed by standardised semivariance and plotted against the distance between locations of catch (Fig. 4). The standardised semivariogram of pre-monsoon sardine yield showed a maximum displacement upto 0.5° lag distance and the maximum fishing activity concentrated at the lag distance between 0° to 0.3° (Fig. 4a). The standardised semivariogram of sardine yield in pre-monsoon season produced a sill and nugget approximately at 1.0° and the variability showed a uniform pattern of fish catch in the entire season and this is well supported in the contour plot of pre-monsoon sardine catch. The standardised semivariogram of sardine yield during monsoon exhibited a wide range of spatial variability ranging between 0° to 0.8° lag distance (Fig. 4b) as compared to other seasons and showed a scattered pattern in the season because of the high rate of variability in the catch and fishing area and the variability of yield, which is plotted in Fig. 2b. The standardised semivariogram (Fig. 4c) of sardine yield during post-monsoon period ranged between 0° to 0.4° and the displacement of points in the semivariogram showed non-uniformity which had more variability than pre-monsoon yield.

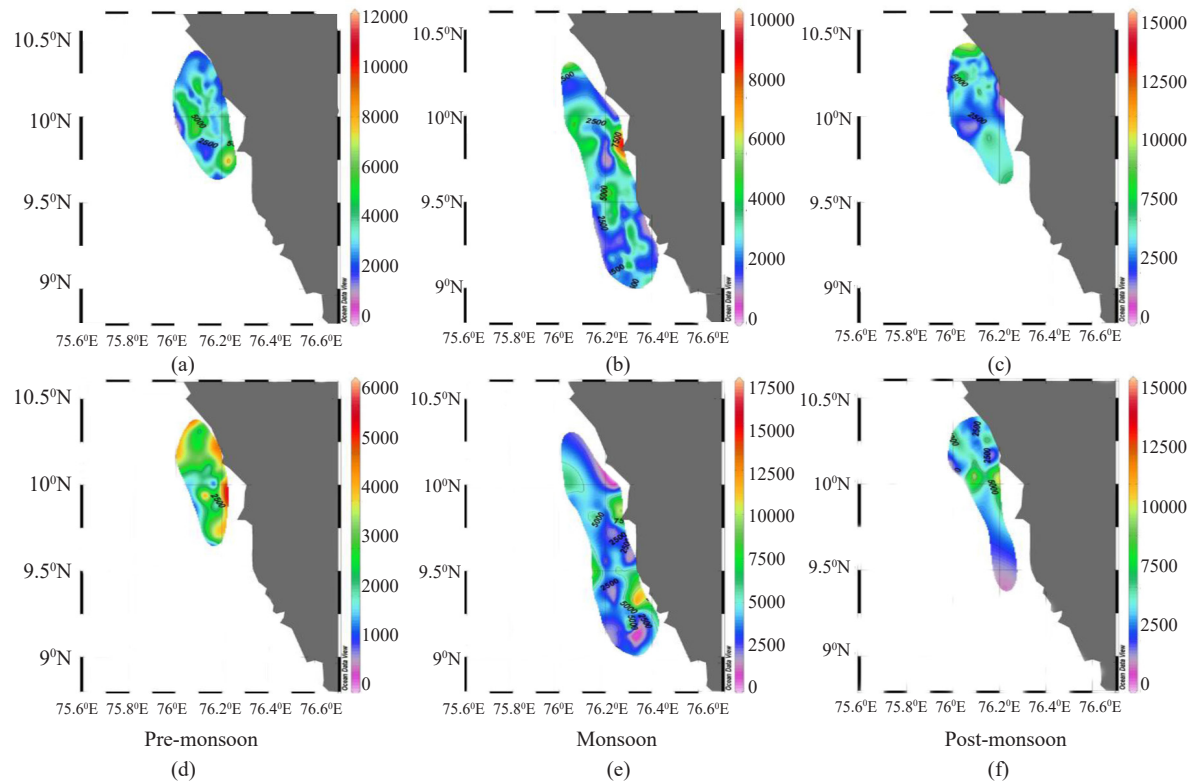


Fig. 2. Contour plot of yield of ring seine. Plots a, b and c represents sardine yield and plots d, e and f represents mackerel yield for pre-monsoon, monsoon and post-monsoon respectively

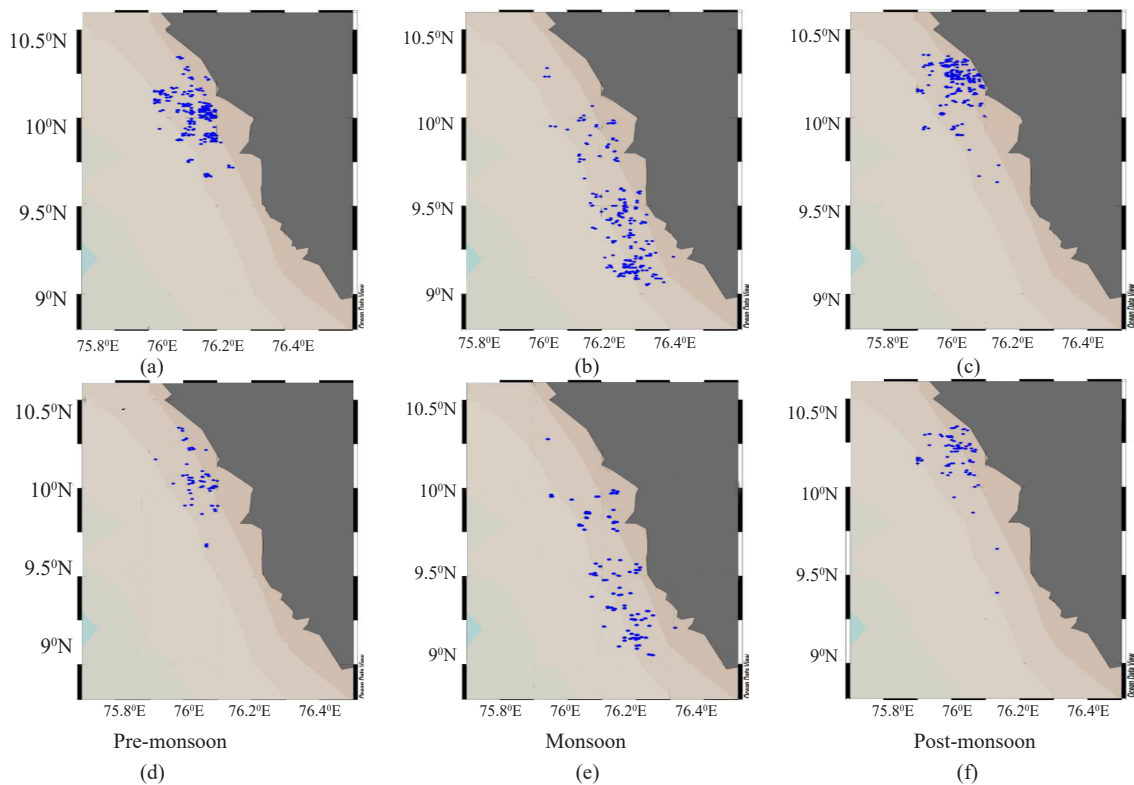


Fig. 3. Seasonal distribution of pelagic fish yields. Plots a, b and c represents sardine yield and plots c, e and f represents mackerel yield for the seasons pre-monsoon, monsoon and post-monsoon respectively

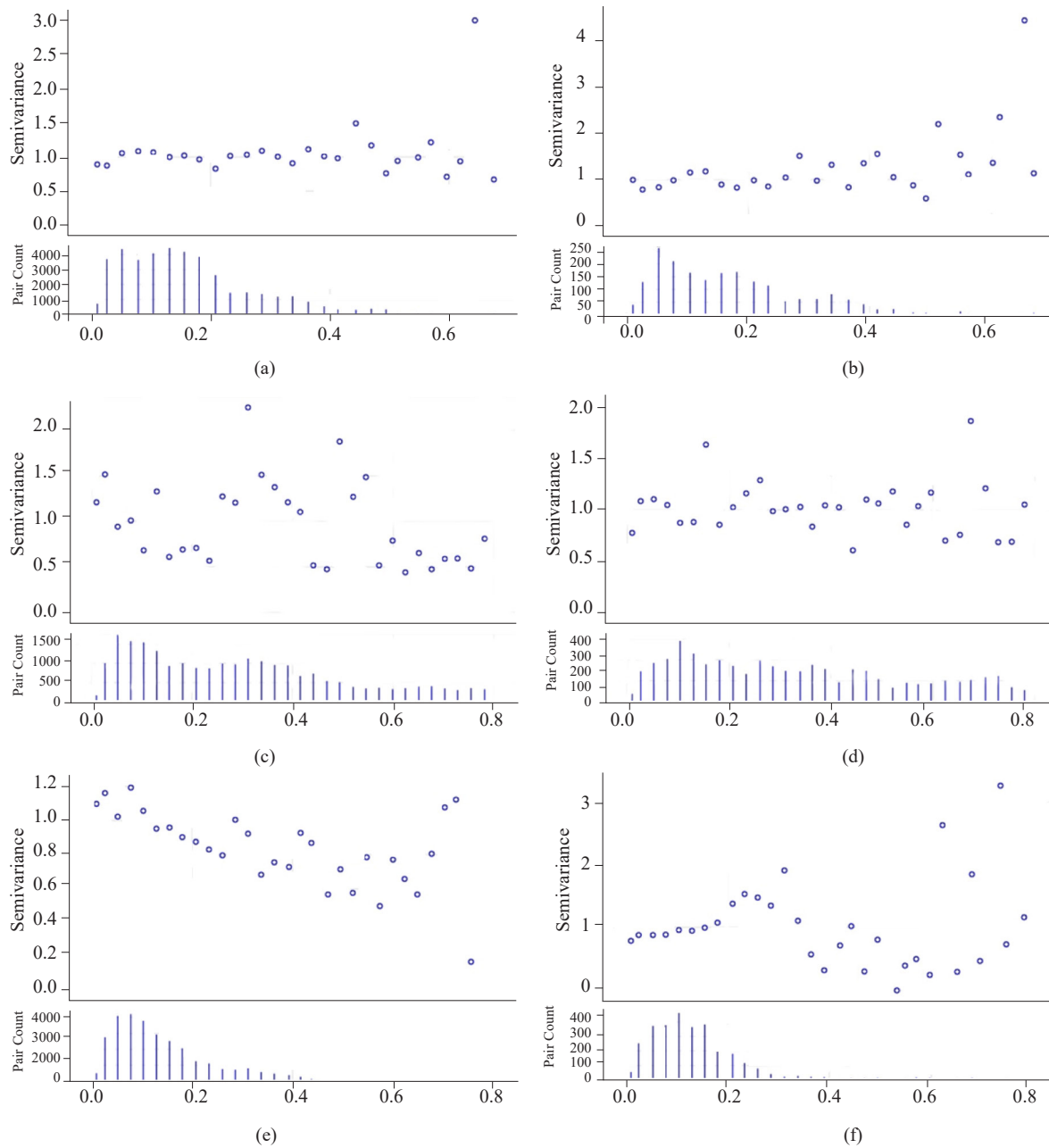


Fig. 4. Empirical semivariogram for fish yield. Plots a, b and c represents sardine yield and plots d, e and f represents mackerel yield for pre-monsoon, monsoon and post-monsoon respectively. The longitudinal distance of fishing area is plotted in X axis against standardised variance of fish yield and pair count frequency in Y axis.

The standardised semivariogram of mackerel yield during pre-monsoon showed a slight increasing trend and the range was between 0° to 0.6° lag distance and had a comparatively higher sill than sardine yield. The area of fish distribution concentrated between 0° to 0.4° lag distance (Fig. 4d). The standardised semivariogram of mackerel yield during monsoon showed a uniform distribution of data points as compared to the sardine yield and the range of fishing

area distribution was observed between 0° to 0.8° lag distance and it is same as sardine yield (Fig. 4e). The standardised semivariogram of mackerel yield during post-monsoon showed a slight increase up to 0.3° lag distance and started decreasing afterwards. The sill of the semivariogram was nearly 2. The fishing area distribution during the season varied between 0° to 0.4° lag distance and maximum concentration was between 0° to 0.2° (Fig. 4f).

The semivariogram showed that pre-monsoon and post-monsoon seasons have less variability with respect to fishing areas than the monsoon season. In monsoon season, the fish shoals are spread across the entire coastal area due to the monsoonal upwelling in the west coast of India. The results of the present study are in conformity with the observations of Pillai *et al.* (2000) who stated that topographical features and meteorological conditions influence the distribution pattern and seasonal abundance of fishes.

The standardised semivariogram showed nearly similar pattern in sardine and mackerel yield for pre- and post-monsoon period, but a southward movement of fishing grounds was observed in monsoon season. Based on these characteristics, it was inferred that the spatial distribution of sardine and mackerel varied with different seasons. The Arabian Sea is considered as one of the highest productive regions in the world oceans (Madhupratap *et al.*, 1996) and shows distinct seasonal variabilities (Madhupratap *et al.*, 1996; Murtugudde *et al.*, 1999; Kumar *et al.*, 2001a, b; Paul and Kumar, 2005; Wiggert *et al.*, 2005; Levy *et al.*, 2007). During monsoon, strong coastal upwelling leads to high productivity along Somalia, Arabia and the south-west coast of India (Kumar *et al.*, 2001a; Wiggert *et al.*, 2005; Levy *et al.*, 2007). This coincides with the fact that during the south-west monsoon season the southern side of Kerala shows a unique nature of fish aggregation phenomenon known as *chakara* (mud bank formation) (Damodaran, 1972; Mathew and Gopinathan, 2000). This area is a feeding and breeding site for many of the pelagic fishes and crustaceans and this may be the reason for the shift of fishery towards the southern region in the monsoon season. The pelagic fishes exhibit vertical migration in post-monsoon and pre-monsoon seasons for avoiding the comparatively warmer surface water (Pillai and Nair, 2010) and this type of vertical migration is not common during monsoon season when surface temperature is low.

GAM of ring seine fishing grounds

The spatial distribution of sardine and mackerel abundance was highly volatile over a range of spatial variables *viz.*, latitude and longitude. The fit summary of the estimated spline parameter and corresponding degrees of freedom of the resultant model for sardine and mackerel yield was plotted. An attempt was made to estimate the sardine and mackerel yield during different seasons in terms of latitude and longitude using GAM (Fig. 5).

It is clearly evident that the ring seine fishing ground shows a displacement with seasons and

the sardine fishery showed a monsoonal south and post-monsoonal reverse movement. In post-monsoon season, the sardine fishery concentrated in the 10.3°N to 10.1°N latitude, after that it moves towards south between 10.1°N to 9.9°N and in monsoon season it spread south from 9.8°N to 9.25°N and again move northwards in post-monsoon season and a reliable pattern of fishing ground displacement between the sardine and mackerel fishing grounds was noticed. Latitudinal fishing positions are similar but longitudinally it showed a negative relationship with yield.

The spatial data of sardine and mackerel yield was modeled as a normal distribution and spline functions of latitude and longitude. The resultant model is given below:

$$\text{Yield}_{\text{Sardine pre-mon.}} = 196.92930 - 0.69364 \text{ lat.} - 2.49522 \text{ long.} + \text{Spline (lat.)} + \text{Spline (long.)}$$

$$\text{Yield}_{\text{Sardine mon.}} = -51.79577 + 0.46296 \text{ lat.} + 0.62201 \text{ long.} + \text{Spline (lat.)} + \text{Spline (long.)}$$

$$\text{Yield}_{\text{Sardine post-mon.}} = 133.13634 + 0.29721 \text{ lat.} - 1.78896 \text{ long.} + \text{Spline (lat.)} + \text{Spline (long.)}$$

$$\text{Yield}_{\text{Mackerel pre-mon.}} = -341.44618 + 1.21786 \text{ lat.} + 4.32355 \text{ long.} + \text{Spline (lat.)} + \text{Spline (long.)}$$

$$\text{Yield}_{\text{Mackerel mon.}} = 30.74675 + 0.08814 \text{ lat.} - 0.41426 \text{ long.} + \text{Spline (lat.)} + \text{Spline (long.)}$$

$$\text{Yield}_{\text{Mackerel post-mon.}} = -39.15303 - 0.11073 \text{ lat.} + 0.52924 \text{ long.} + \text{Spline (lat.)} + \text{Spline (long.)}$$

The fit summary of the estimated spline parameter and corresponding degrees of freedom of the resultant model for sardine and mackerel yield for different seasons is given in Table 1.

The linear component of latitude of sardine yield produced a significant effect at 5% level of significance. The other linear parameters of sardine and mackerel yield were found to be non-significant. The parametric and non-parametric parameters of back fitting algorithm of sardine and mackerel yield converged satisfactorily.

The smoothing component of sardine yield with respect to the latitude and longitude was a quadratic and complex function respectively. The spline smoothing function of latitude and longitude with 95% confidential limits is given in Table 1. The spline smoothing parameter for both the covariates was significant at 5% level of significance.

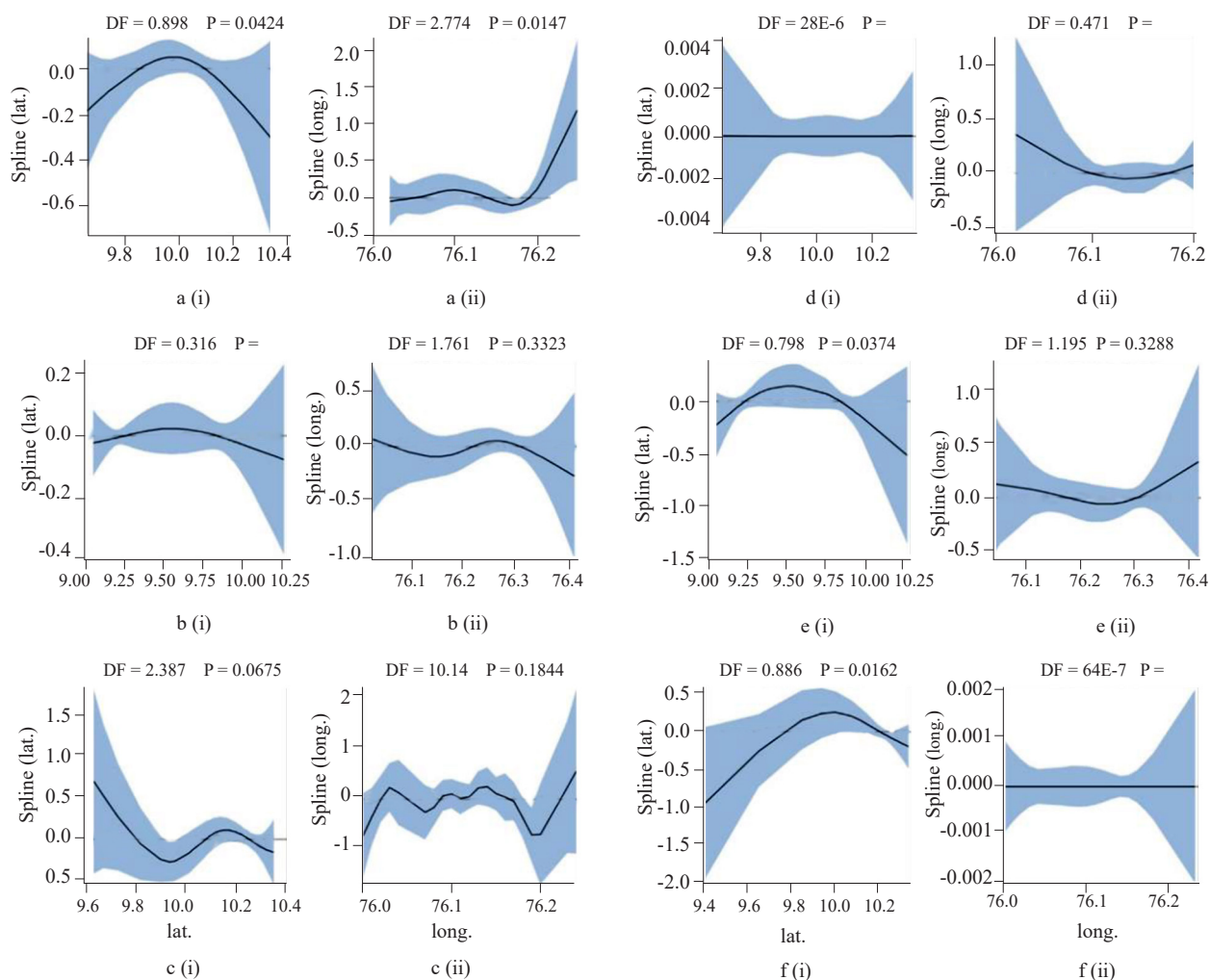


Fig. 5. Smoothing component of ring seine yield. Plots a, b and c represent sardine yield and plots d, e and f represent mackerel yield for the seasons pre-monsoon, monsoon and post-monsoon respectively. The latitude and longitude plots are in i and ii respectively in X axis against spline function of the X axis in the Y axis.

Table 1. Fit Summary for Smoothing Components of yield

Component	Smoothing parameter	DF	GCV	Sum of squares	Chi-square	Pr>ChiSq
Sardine pre-mon. spline (lat.)	1.00	0.90	0.48	3.72	3.85	0.04
Sardine pre-mon. spline (long.)	0.99	2.77	0.53	9.71	10.06	0.01
Sardine mon. spline (lat.)	1.00	0.32	0.48	0.55	0.55	
Sardine mon. spline (long.)	1.00	1.76	0.28	1.90	1.91	0.33
Sardine post-mon. spline (lat.)	1.00	2.39	0.47	5.92	6.09	0.07
Sardine post-mon. spline (long.)	0.47	10.14	0.19	13.54	13.92	0.18
Mackerel pre-mon. spline (lat.)	1.00	0.00	0.86	0.00	0.00	
Mackerel pre-mon. spline (long.)	1.00	0.47	0.55	1.09	1.10	
Mackerel mon. spline (lat.)	1.00	0.80	1.04	3.75	3.78	0.04
Mackerel mon. spline (long.)	1.00	1.19	0.18	1.20	1.21	0.33
Mackerel post-mon. spline (lat.)	1.00	0.89	1.24	5.27	5.45	0.02
Mackerel post-mon. spline (long.)	1.00	0.00	0.67	0.00	0.00	

These analyses indicated strong geographic effects on small pelagic fishery catch rates, with predominance of latitude effect. The pelagic fish vertical migration in

post-monsoon and pre-monsoon seasons for avoiding the warmer surface water (Pillai and Nair, 2010) and the unique nature of fish aggregation phenomenon

during the south-west monsoon season in the southern side of Kerala coast (Damodaran, 1972; Mathew and Gopinathan, 2000) influenced the distribution of pelagic fish in these areas.

Bigelow *et al.* (1999) developed a GAM for blue shark catch rates from logbook data and found that latitude, longitude and sea surface temperature were the most important predictor variables. Walsh and Kleiber (2001) studied the GAM including nine spatio-temporal, environmental and operational variables explained 72.1% of the deviances of the blue shark catch rates and the author reported that latitude exerted the strongest effects of any individual variable. In the present study, similar latitudinal effect of fish abundance on small pelagic fish yield in different seasons was observed.

Until now, spatial distributions of sardine and mackerel abundance have been based mainly on the fishers' assumption of locations. Spatial models of catch dynamics with spatial data allow more accurate prediction of fisheries management measures. The catch data modeling is able to predict the consequences of future management actions. The regional model developed in the study will help in predicting abundance and spatial distribution with reference to latitude and longitude. The main application would be in reducing search time and fuel consumption.

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