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Effect of tropical monsoon on fishery abundance of Indian squid (*Uroteuthis* (*Photololigo*) *duvaucelii*)

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ABSTRACT

Indian squid, ***Uroteuthis* (*Photololigo*) *duvaucelii*** (Loliginidae) constitute an important component of the inshore cephalopod fisheries along the eastern Arabian Sea. Local environmental variation plays an important role in species–environment interactions in neritic squids, which inhabit nearshore/coastal waters. Such 'active' and 'passive' responses of squids to environmental changes is crucial in understanding their relationships and influence on the biological processes, distribution and abundance of the fast-growing short-lived coastal loliginids. The empirical relationship between squid abundance and the variability in rainfall and sea surface temperature (SST) were explored in a tropical monsoon fishery. Monthly catch rates (catch per fishing hour) of squids in commercial trawl during 1987–2009 were used as the abundance index. Linear regression models with ARIMA errors were fitted with catch per unit hour time series as dependent variable and rainfall and SST as exogenous variables. While rainfall was observed to have a negative effect on squid abundance, the SST recorded a positive impact. ARIMA models provided satisfactory fit to observed data and forecast of 22 months. Given that the squid life-cycle is a function of their environment, this result is relevant in forecasting squid biomass for the management of tropical monsoon fisheries.

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Loliginidae; Arabian Sea; monsoon; temperature; abundance; time-series

Introduction

Indian squid, *Uroteuthis* (*Photololigo*) *duvaucelii* (F. Loliginidae) is a neritic species forming a major component of the artisanal squid fishery in the Indo-Pacific region. The species occurs on the continental shelf and constitutes a significant commercial fishery in India, Thailand, the Andaman Sea and Gulf of Aden (Arkhipkin et al. 2015). The Indian squid is the most important cephalopod species exploited by the bottom trawl fleets in the eastern Arabian Sea bordering the west coast of India. Directed trawl fishery for loliginids in this region emerged during the early 1990s, driven by the demand in global export trade (Sasikumar and Mohamed 2012), with most of the frozen and value-added products destined for Europe. The only regulation of fishing effort in the region at

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present is the implementation of yearly closure of mechanized fishing for a period of 47 days commencing from June 15 to July 31.

Loliginid squids are characterized by extreme plasticity in life-histories, with fast growth rates and short life-span in response to environmental or oceanographic conditions (Jackson and O'Dor 2001; Pecl and Jackson 2008). The environmental sensitivity of squids is correlated to multiple drivers influencing distribution, abundance (Rowell et al. 1985) and migration to favoured feeding environments (Martins et al. 2006; Martins and Perez 2007) or to areas which maximize spawning success (Sauer et al. 1991; Roberts and Sauer 1994; Cabanellas-Reboredo et al. 2012). The importance of environmental variability as a potentially significant factor in determining the stock fluctuations in squids has been highlighted in loliginids (Roberts 1998, 2005; Chen et al. 2006). Therefore, the analysis of environmental variables to examine trends in abundance of squid has received greater interest over the past few years (Postuma and Gasalla 2010; Rodhouse et al. 2014).

Typically, loliginids remain dispersed over the continental shelf during the major part of their life cycle. Mature squids undertake spawning migrations to inshore spawning grounds (Worms 1983) for congregation and egg laying, and commercial and artisanal fisheries take advantage of these aggregations (Mohamed 1993; Schön et al. 2002; Iwata et al. 2010; Postuma and Gasalla 2010). In the eastern Arabian Sea, *U.* (*P.*) *duvaucelii* spawning occurs throughout the year with seasonally intense activity during September to November (Silas et al. 1985; Mohamed 1993). A similar pattern in spawning migration is reported for other loliginid species (*L. reynaudii* in South Africa – Sauer et al. 1991; Roberts 1998).

Spawning aggregations of fully mature animals (80% males) occur annually in near-shore spawning grounds during September–October in varying intensities (Mohamed 1993). This species is subjected to heavy fishing pressure by trawl fishing fleets during the critical spawning and post-spawning stages. The female squids spawn in shallow waters with sandy or hard substratum immediately after the spawning congregation. The occurrence of egg mops in gelatinous finger-like strands attached to the substratum in shallow intertidal areas (Asokan and Kakati 1991) indicates reproduction in coastal benthic habitats.

The Arabian Sea, the north-western part of Indian Ocean (Western Indian Ocean) is a tropical basin known to experience a monsoon wind force and corresponding semi-annually reversing surface circulation. Corresponding to the regular monsoon, this near-shore fishing area in the Arabian Sea experiences changes in physical, chemical and biological parameters. During summer monsoon, starting from May/June the direction of the monsoon wind is south-westerly and in winter, from November, it is north-easterly. In comparison with the rest of the Indian Ocean, the western Indian Ocean generally has cooler mean sea surface temperatures (SSTs) in summer, owing to the strong monsoon winds and upwelling over the west (Roxy et al. 2015). The processes associated with monsoons make the Arabian Sea one of the most biologically productive regions of the worlds' oceans (Ryther et al. 1966). On a regional scale, the eastern Arabian Sea (west coast of India) has high mean and high variability in rainfall (Goswami et al. 2006). The local orography of coastal areas also has a strong influence on the rainfall. The region experiences winter from December to February.

The coastal upwelling during the summer monsoon in the Arabian Sea is well documented (Johannessen et al. 1981), and is characterized by decreased SSTs, increased concentrations of nutrients and reduction in dissolved oxygen levels. Besides the reduction in SST, upwelling and the related horizontal advection alter the physical and chemical properties of water due to the offshore transport of coastal waters, and the occurrence of more saline and denser hypoxic water (<0.5 ml dissolved oxygen/litre) in the surface. The neritic Indian squid populations in these near-shore coastal waters are therefore exposed to the highly dynamic environmental conditions prevailing in the region.

Considering the short life-span of the Indian squids and their exploitation in the highly dynamic inshore region, it is imperative to understand the effect of environmental changes on the level of inter-annual abundance. Among environmental factors, the seawater temperature is considered as the key influencing parameter, as large changes in growth patterns are indicated by small changes in water temperature (Forsythe 1993; Moreno et al. 2007). The influence of temperature has been related to the variability in squid abundance, availability of spawning grounds (Augustyn 1990; Pierce and Boyle 2003; Postuma and Gasalla 2010) the strength of the spawning activity (Sauer et al. 1991) the onset of migrations (Sims et al. 2001) and many other aspects in squid life histories (see Pierce et al. 2008).

Correlations of SST and other environmental parameters with catch rates are potentially important for developing forecasts to support the management of fisheries (Pierce et al. 2008). Furthermore, in the context of changing oceanic conditions due to climate change, such analysis is relevant in defining the role of environmental variables in the regulation of year-class strength. Therefore, the focus of this study was to understand the empirical relationship between the effect of the variability in rainfall and SST on neritic squid abundance in order to envisage the response of squid catches in changing environmental conditions.

Materials and methods

Squid samples were collected from trawls operating in the eastern Arabian Sea. The data were collected by recording the catch and fishing hours from the two major and five minor fishing harbours located between Karwar and Mangalore (Figure 1) during January 1987–October 2011. Monthly catch and effort were estimated following a multi-stage random sampling design (Srinath et al. 2005). Briefly, the method involves observations of catch (kg/trawl) and effort (h) for a 24 h period in a randomly selected sampling day. These squid daily catches and effort from at least 10% of the vessels were multiplied with the number of vessels on the observation day to arrive at the daily estimate. To obtain the monthly catch and effort estimates, the daily data from the sampling days in a month were pooled and multiplied by the number of fishing days in a month. The catch-per-unit-hour, in terms of catch (kg) per trawling hours (CPH) was used as an index of abundance.

A regression model with autoregressive integrated moving average (ARIMA) errors was used to study the influence of SST and rainfall on the squid abundance. The existence of collinearity between the variables (SST and Rainfall) was evaluated by estimating the variance inflation factor (VIF). The VIF represents the proportion of variance in one predictor explained by all the other predictors in the model (Heiberger and Holland 2004). A VIF = 1 indicates no collinearity, whereas increasingly higher values suggest collinearity.

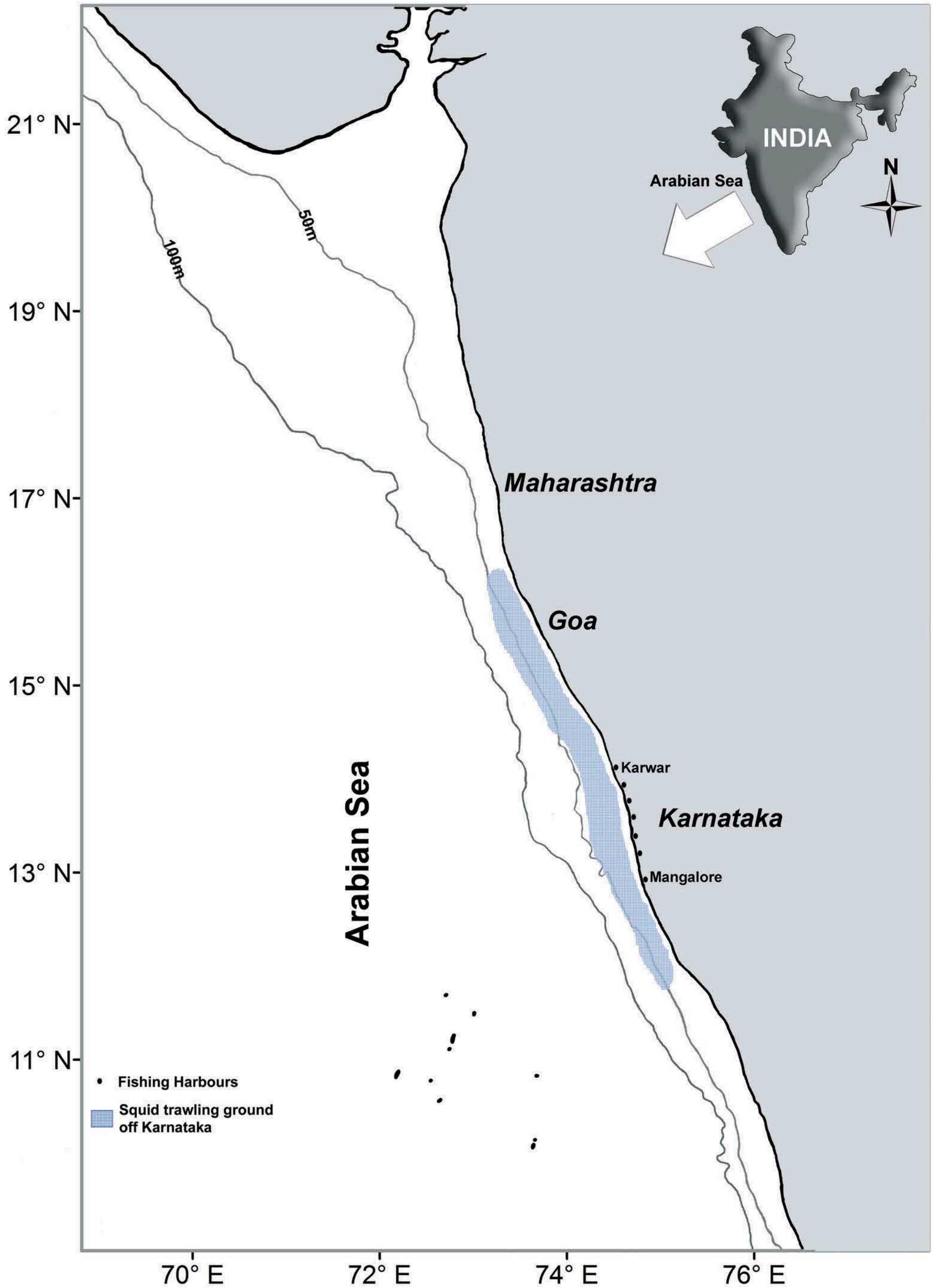

Figure 1. Map showing the trawling ground (hatched area) of *U.* (*P.*) *duvaucelii* off Karnataka.

The monthly mean SST (°C) dataset in the Arabian Sea (12–16°N and 73–75°E) was extracted for the period 1985–2011 from International Comprehensive Ocean-Atmosphere Data Set (ICOADS: Release 2.4). Rainfall (mm) data was procured from

India Meteorological Department (IMD). As an index of abundance, data on monthly catch (kg) per trawling hours (CPH) of squids was used. Since there is no abundance data during the fishery closure, the data in July were not considered for model building.

The catch per unit hour data of monthly observations (anomalies) were fitted to an additive linear regression model:

$$y_t = \beta_0 + \beta_1 x_{1,t} + n_t \quad (1)$$

where y_t is the catch per unit hour for the month t and it is a linear function of the predictor variable SST or rainfall denoted as $x_{1,t}$, β values are regression coefficients and n_t is the error term. The error series n_t was assumed to follow an ARIMA model and it was expressed as $\left(1 - \varphi_1 B - \ldots - \varphi_p B^p\right) n_t = \left(1 + \theta_1 B + \ldots + \theta_q B^q\right) e_t$, where e_t is the uncorrelated error term. An in-depth discussion on ARIMA models is given in Box et al. (2015), Pankratz (1983) and Wei (1994). ARIMA model requires a stationary data series. In practice, stationarity means that the data series has a constant mean and variance through time. The mean of a non-stationary series can often achieve stationarity by differencing and the variance by means of a logarithmic or other transforming algorithm (Hanson et al. 2006).

Verification of model assumptions was carried out by evaluating the normal distribution of the residuals. The time series were tested for stationarity using popular unit root test Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test (Kwiatkowski et al. 1992). Based on the test it was found that CPH series was non-stationary while stationarity was accepted for SST and rainfall series. Since CPH series was non-stationary, differencing of the series was done and KPSS test was repeated. The resulting series was stationary and was used for model building. Validation of the model was made using data for the period January 2010 to October 2011. The statistical procedures mentioned in the present study were implemented using the statistical computing environment R (R Core Team 2015).

Models with different orders of autoregressive coefficient (AR) and moving average coefficient (MA) were evaluated by comparing bias-corrected Akaike's information criterion (AICc). Various diagnostic checks were performed to test the assumption of uncorrelated random residuals with a zero mean and constant variance and accuracy measures to evaluate the forecasting power of the models. Assumptions of independent and identically distributed residuals were verified using the Ljung–Box test (Ljung and Box 1978). Forecasting accuracy was assessed based on root of the mean square error (RMSE) and mean absolute error (MAE).

Results

Annual catch of *U.* (*P.*) *duvaucelii* recorded an increase from an average of 2,393 t during 1987–1991 to an average of 8,406 t during 2007–2011 (Figure 2). The annual average SST ranged between 28.08 and 29.14°C (Figure 3). A gradual warming of seawater was observed after winter (December–February) from March, and this continued to increase till May. Relatively warmer SST prevailed during April–May. This was followed by a dip from June to August, with August recording the lowest temperature. A gradual warming of seawater was yet again recorded from September, and this continued to increase until the drop in SST from December to February (Figure 4). The mean monthly rainfall was

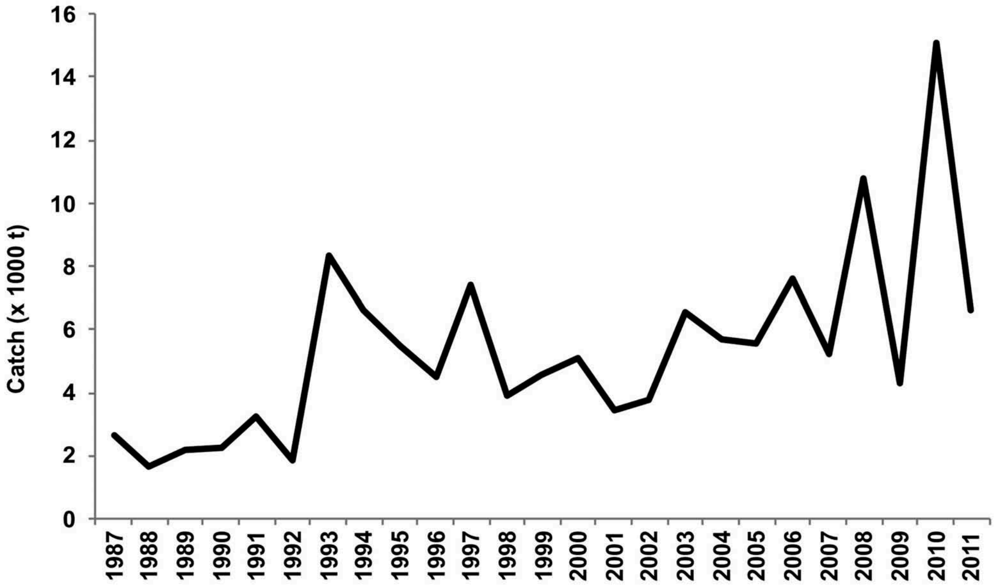

Figure 2. Annual time series of squid catch during 1987–2011 indicating the catch trend.

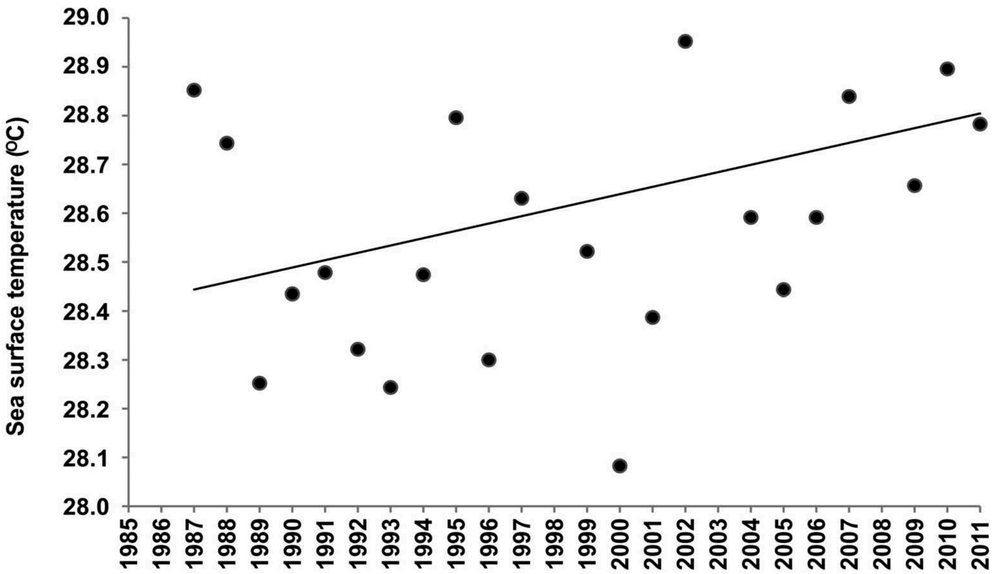

Figure 3. Time series of sea surface temperature (°C) during 1987–2011.

highest during June–August (Figure 5). An increasing trend in catch rate of squids was apparent from 2.8 kg h^{-1} in February to 5.1 kg h^{-1} in March; similarly, from 1.4 kg h^{-1} in August to 3.7 kg h^{-1} in September.

The linear regression model with SST as dependent variable and rainfall as independent variable, fitted using least squares approach and VIF, was calculated as 1.019, indicating that there is no correlation between the two variables.

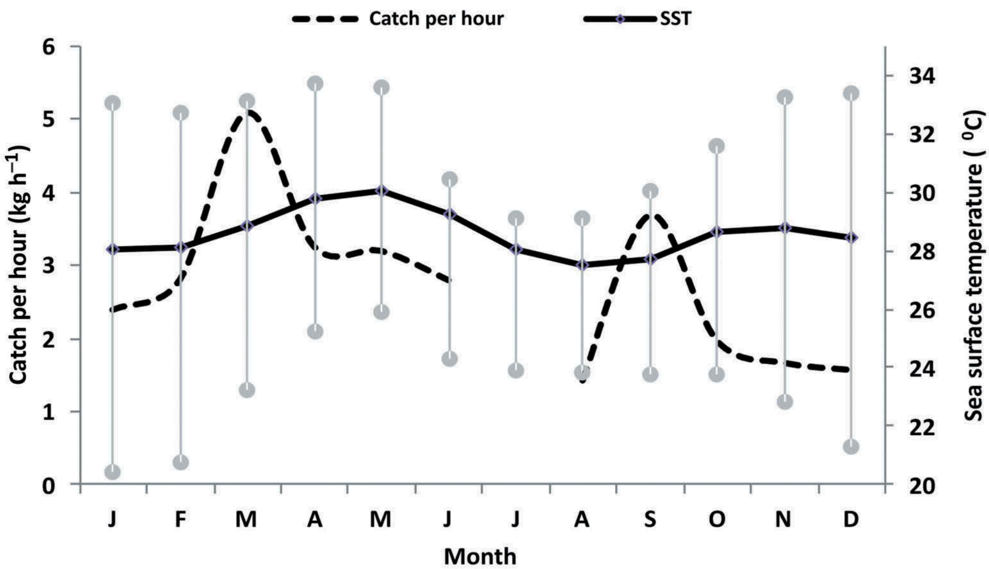

Figure 4. Monthly mean squid CPH and sea surface temperature (°C) with error bar denoting temperature maximum and temperature minimum.

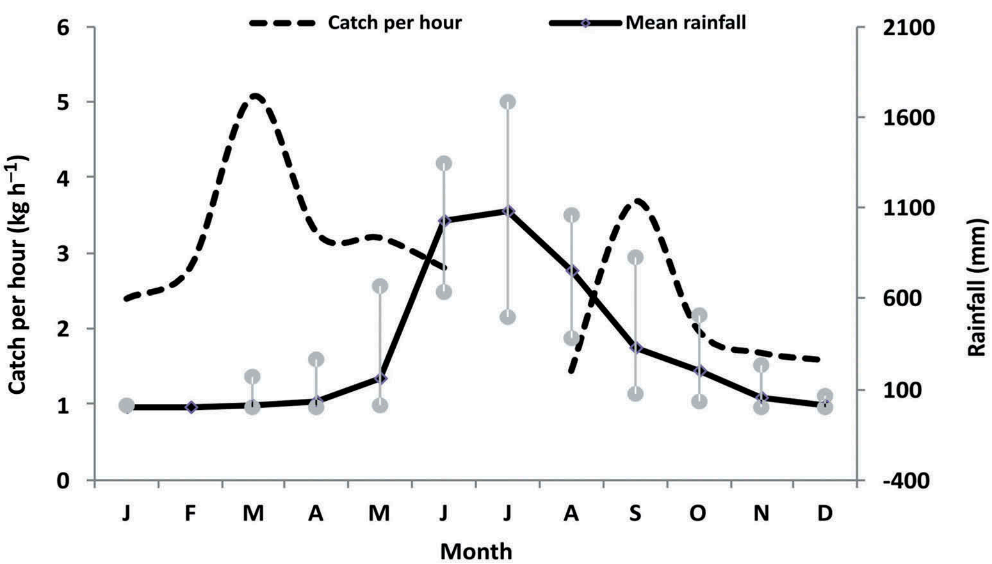

Figure 5. Monthly mean squid CPH and rainfall (mm) with error bar denoting rainfall maximum and rainfall minimum.

The regression model with ARIMA (2,1,2) was found suitable for representing CPH, when the linear regression model with ARIMA errors were fitted using CPH as dependent variable and SST and rainfall series as independent variables. The models with one independent variable at a time performed well, when compared to the one combining SST and rainfall. Hence SST or rainfall was independently considered for further analysis.

The most suitable model for representing CPH using rainfall was ARIMA (3,0,1) [Model 1] and with SST was ARIMA (5,1,0) [Model 2]. For the selected models, the minimum AICc value corresponded to model 1 (Table 1). In model 1, the coefficient measuring the effect of rainfall on CPH was negative. Based on this, an estimated reduction of 0.0018 kg on squid abundance has been predicted for every 1 mm increase in rainfall. In the case of model 2, the effect of SST on squid abundance is positive. The predicted impact of increase in an extra degree of SST can be modelled to have an increase in abundance (CPH) by 0.073 kg in a given month.

For a good forecasting model, the residuals left over after fitting the model should be white noise. The Ljung–Box test is applied to the residuals of the fitted models and results indicated acceptance of accuracy of models at 95% significant levels. Model 1 is the preferred model according to the four evaluative measures, i.e. root mean squared error (RMSE), mean absolute error (MAE), mean percentage error (MPE) and mean absolute percentage error (MAPE) (Table 2). Based on these values, model 1 performed better than model 2. The forecasted series using the developed model 1 is presented in Figure 6.

The present study shows that the fitted models have the capacity to capture the fluctuations in the series and are thus appropriate for modelling, although model 1 has more forecasting accuracy than the other.

Table 1. Summary of results for the fitted ARIMA model for the 1995–2008 dataset.

Explanatory variable	Parameter	Estimate	SE	AIC AICc & BIC
SST (Model 2)	AR1	−0.3969	0.0807	878.21
	AR2	−0.5444	0.0864	878.69
	AR3	−0.3105	0.091	902.54
	AR4	−0.191	0.0731	
	AR5	−0.1536	0.0688	
	SST	0.0731	0.1573	
Rainfall (Model 1)	AR1	0.3765	0.5032	832.37
	AR2	−0.2736	0.23	832.85
	AR3	0.0899	0.1486	856.73
	MA1	0.0938	0.0005	
	RAIN	−0.0018	0.1726	
	Intercept	−0.383	0.2515	

AR1: autoregressive coefficient of order 1; MA1: moving average coefficient of order 1; AIC: Akaike's information criterion; AICc: bias-corrected Akaike's information criterion; BIC: Bayesian information criterion.

Table 2. Forecasting accuracy parameters for the fitted ARIMA model.

Explanatory variable	Accuracy statistics	
SST	RMSE	1.9938
	MAE	1.3676
	MPE	73.514
	MAPE	255.29
Rainfall	RMSE	1.7874
	MAE	1.2231
	MPE	31.28
	MAPE	156.2

RMSE: root mean squared error; MAE: mean absolute error; MPE: mean percentage error; MAPE: mean absolute percentage error.

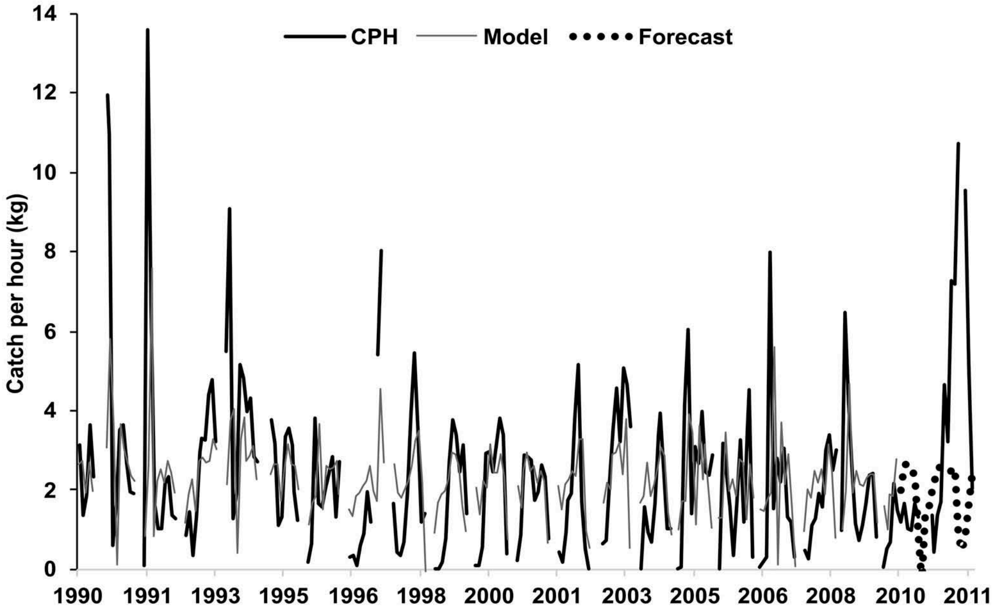

Figure 6. The forecasted series of catch (kg) per hour (CPH) using the developed model 1.

Discussion

The analysis of variability in catch rates of *U*. (*P*.) *duvaucelii* in relation to the environmental parameters highlighted the influence of rainfall and SST on squid abundance. The trends in neritic squid abundance, in near-shore fishing grounds were negatively related to rainfall, and positively with SST.

In the Arabian Sea, the south-west monsoon winds of oceanic origin get established in May and are strengthened in June. During July and August, the winds are further strengthened (~7 m s^{-1}) over the entire coast and continue up to the end of September, until the withdrawal of the summer monsoon along the west coast of India (Naidu et al. 1999). The onset of monsoon is associated with overcast skies, precipitation, strong winds and turbulence. In addition, the shelf regions are subjected to increased river discharge, resulting in monsoon associated changes in physical, chemical and biological properties. The synoptic patterns and atmospheric dynamics of summer monsoon are highly complex and have been the subject of numerous studies (Goswami et al. 2011; Turner and Annamalai 2012; Sooraj et al. 2014; Roxy et al. 2015).

In upwelling areas, the oceanographic events can be an important factor determining cephalopod distribution and abundance. The relationship between coastal upwelling events and squid abundance have been reported for *Loligo reynaudii* in the south-eastern coast of Africa (Roberts and Sauer 1994). The SST is suggested to be the most reliable indicator of the coastal upwelling in the Arabian Sea (Prell and Curry 1981). Reduction in SST with the incursion of upwelled water into the surface layers was evident in the study area, indicating the occurrence of coastal upwelling during the summer monsoon. The occurrence of cold upwelling water can restrict distribution of warm water species in the area. Squid may select an optimum temperature range to spawn by undertaking spawning migrations in an attempt to maximize hatching success (Cabanellas-Reboredo et al. 2012). Studies of *Loligo reynaudii* off South Africa highlight the importance of turbidity and dissolved oxygen in determining the availability of squid on the ground and in locating the preferred conditions for spawning sites (Augustyn et al. 1994). Oxygen tension is considered important for egg development and survival in loliginid squids, where the large size of egg masses is likely to restrict water flow in embryos located near the attachment point, causing hypoxic conditions and higher occurrence of developmental abnormalities (Murray 1999). It is likely that there is similar strong link between recruitment of Indian squids and favourable oceanographic conditions, mainly temperature, as emphasized in several studies (Pierce et al. 2008).

The sandy bottom of inshore waters is subjected to strong monsoon waves and upwelling. The cumulative effect of this process exerts heavy siltation (Fernandez 1996) and physical changes under monsoon conditions. Though fully mature squids are caught throughout, signifying protracted recruitment to the fishery, peak spawning pulse and major recruitment in post-monsoon seems to be influenced by the intensity and/or duration of rainfall events. Rainfall also indirectly affects the availability of squids in inshore waters due to changes in salinity (Lefkaditou et al. 1998). The prolonged duration or increased rainfall intensity and continuous turbulent sea condition may prevent spawners from reaching their preferred spawning locations that are suitable for egg laying, development of eggs or survival of paralarvae, or a combination of all these. It has been reported that loliginids have a preferred spawning habitat (Cabanellas-Reboredo et al. 2014), having more favourable environmental conditions, which may enhance paralarval survival. Eventually, the variability and unexpected changes in the ecosystem could either weaken or strengthen the inherent biological advantages, and ultimately impact recruitment (Roberts 2005). Though the movement of squid within the inshore waters, as documented in other loliginids (Pecl et al. 2006; Downey et al. 2009; Cabanellas-Reboredo et al. 2012), is currently not subjected to any detailed investigation in Arabian Sea, the occurrence of juvenile squids was reported by fishermen from commercial fishing grounds in considerable quantities at depths ranging from 60–65 m during late November to January months.

The retreat of summer monsoon and associated environmental changes from September, including decrease in cloud cover, upwelling, river discharge and precipitation, result in a marked increase in both primary and secondary productivity. This in turn could alter the pattern in abundance of Indian squid in coastal waters and set the stage for spawning aggregation and egg laying. A similar pattern has been documented in the temperate loliginid *Loligo reynaudii*, where a synchronization of egg laying and productivity occurs so that the hatchlings emerge at the peak of production, also coinciding with an increase in temperatures. Similarly, depending on the sea temperature, European squids are reported to move from deeper waters to inshore waters (Cabanellas-Reboredo et al. 2014). This may enable the hatchlings to grow, by taking advantage of the abundance of prey (Sauer et al. 1992; Roberts 2005). For eggs spawned at this period, the embryonic phase is associated with a gradual warming of water temperature, facilitating reduced incubation period and early hatching. Such timing in spawning suggests adaptation of reproductive strategy to suit local environmental process. Any de-synchronization of peak spawning and peak productivity may therefore have implications for juvenile growth rate and survival (Pecl and Jackson 2008), affecting recruitment. The variability in rainfall patterns, relating to duration, intensity and frequency appear to have a direct influence on the extent of inshore spawning.

Correlations between fishery yield and temperature in different seasons has been related to the effect of temperature variability on paralarval survival, growth rate, benthic settlement and timing of reproduction (Caballero-Alfonso et al. 2010). Recruitment strength of cephalopods is often related to environmental temperatures during the earlier part of life (Pierce and Boyle 2003). The peaks in Indian squid abundance occur while the temperatures are increasing in near-shore waters, coinciding with the retreating monsoons in September and during the transition from winter to summer in March. During September–October, congregation of larger mature squids (dorsal mantle length, 105–245 mm) in the near-shore waters suggests near-shore migration to spawning grounds for pre-spawning aggregations (Mohamed 1993). The presence of squid mops in the coastal waters during the same period provides evidence of egg laying on the nearshore substratum (Asokan and Kakati 1991). Therefore, the variations in squid abundance in near-shore regions are more likely due to the direct influence of temperature on the biological processes such as spawning, migrations and egg/larval survival, leading to recruitment success. The negative influence of rainfall indicates, to some extent, the indirect effect of monsoon on the habitat characteristics as well as on the environmental variables, especially SST and dissolved oxygen, indirectly influencing the squid availability.

The variability in abundance reinforces the influence of environmental changes on squid population. The temperature limits of Indian squids are not known exactly. In general, the inshore loliginids are exposed to fluctuating environmental conditions and appear to be more adaptable to changes in the environment. Squids are known for the extreme plasticity in their life-cycle. This is principally due to the response of squid physiology to environmental variables, among which temperature has been cited as a key driving element (Moreno et al. 2007; Pecl and Jackson 2008). Growth strategies in loliginid squids are subject to fluctuating near-shore environments, as apparent in seasonal statolith ageing studies (see Pecl and Jackson 2008). Therefore, as evidenced in the present study, a tentative assessment can be made on the response of squid stocks to modelled predictions, based on the negative effect of rainfall and associated reduction in temperature or on positive effect of SST on catch rates.

The consequences of overall variability in environment associated with rainfall was observed to be a better predictor of squid abundance, rather than the changes in temperature.

This primary analysis of environmental variations in Arabian Sea in relation to the abundance of *U.* (*P.*) *duvaucelii* is an initial step in the development of predictive tools useful for resource management in this tropical region. Assessing and managing squid stocks using classical stock assessment requires precise ageing of the short-lived assemblage of fast growing micro-cohorts. Furthermore, in contrast to the conventional stock management methods involving multi-age structured fishery resources, the short-lived cephalopods require assessment and management on a shorter time-scale, often necessitating in-season assessment and real-time management of cephalopod populations (Pierce and Guerra 1994).

Currently the resource specific management is limited to the minimum legal size at harvest (Mohamed et al. 2014), apart from the seasonal fishery closure. The most common means of managing cephalopod fisheries is by regulating fishing effort, which will reduce the risk of recruitment overfishing (Rosenberg et al. 1990). Although some approaches to stock assessment are not applicable in cephalopods, Pierce and Guerra (1994) indicated the usage of time-series models incorporating environmental information for successfully managing this fishery. The existing mechanized fishery closure may not be an effective method for regulation of fishing effort as it coincides with the period of reduced squid abundance during monsoon. The annual fluctuations in catches and catch rates, especially during periods of low biomasses, can impact the squid stocks. An understanding of the relationship between squid catches and the environment might enable to forecast these fluctuations, to regulate fishing effort for the advantage of biological and economical objectives.

Squid landings are closely related to environmental conditions in many squid species (Robin and Denis 1999; Sakurai et al. 2000). However, the indirect effect of monsoon on tropical squids is not well documented, and our understanding on the long-term sustainability of these commercial species in a changing climate scenario is limited. Analysis of rain gauge data shows that Indian monsoon rainfall has remained stable over the past century even though the global mean surface temperature has risen steadily. Though there is strong evidence of an increase in the number of extreme monsoon weather events over India during the past half century, the seasonal mean monsoon rainfall remains stable, because the contribution from increasing heavy events is offset by decrease in moderate rainfall events (Goswami et al. 2006). A recent study comparing present observations and future regional climate model projections of the summer monsoon suggests a further weakening of the monsoon circulation and Indian peninsular rainfall in the future (Dash et al. 2015). Meanwhile, studies based on the Coupled Model Inter-comparison Project phase 5 (CMIP5) projections suggest an increase in rainfall over the central Indian subcontinent (Sharmila et al. 2015). The Intergovernmental Panel on Climate Change (IPCC) suggests that there are uncertainties looming over the status and fate of the monsoons (Christensen et al. 2013), despite the advancement in analysis and modelling of the variability in monsoons. Within these complexities and uncertainties, the overall squid abundance is predicted to reduce with increase in rainfall (Model 1) and squid biomass is predicted to increase with SST (Model 2). Such linearity in response observed in theoretical modelling between the physical and biological processes may not prove that squid abundance is merely controlled by rainfall and temperature. Further research is needed for a better understanding of the changes in distribution and migration patterns, and in the reproduction process under different environmental regimes, integrating social, economic and ecological considerations.

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References

Arkhipkin AI, Rodhouse PGK, Pierce GJ, Sauer W, Sakai M, Allcock L, Arguelles J, Bower JR, Castillo G, Ceriola L, et al. 2015. World Squid Fisheries. Rev Fish Sci Aqua. 23(2):92–252.
Asokan PK, Kakati VS. 1991. Embryonic development and hatching of *Loligo duvaucelii* Orbigny (Loliginidae, Cephalopoda) in the laboratory. Indian J Fish. 38(4):201–206.
Augustyn CJ. 1990. Biological studies on the Chokker squid *Loligo vulgaris reynaudii* (Cephalopoda; Myopsida) on spawning grounds off the south-east coast of South Africa. Afr J Mar Sci. 9:11–26.
Augustyn CJ, Lipinski M, Sauer W, Roberts M, Mitchell-Innes B. 1994. Chokka squid on the Agulhas Bank: life history and ecology. S Afr J Sci. 90:143–154.
Box GEP, Jenkins GM, Reinsel GC, Ljung GM. 2015. Time series analysis: forecasting and control. 5th ed. Hoboken (NJ): John Wiley and Sons Inc; p. 712.
Caballero-Alfonso AM, Ganzedo U, Trujillo-Santana A, Polanco J, Santana del Pinoa A, Ibarra-Berastegic G, Castro-Herna´ndez JJ. 2010. The role of climatic variability on the short-term fluctuations of octopus captures at the Canary Islands. Fish Res. 102:258–265.
Cabanellas-Reboredo M, Alós J, Palmer M, Morales-Nin B. 2012. Environmental effects on recreational squid jigging fishery catches. ICES J Mar Sci. 69:1823–1830.
Cabanellas-Reboredo M, Calvo-Manazza M, Palmer M, Hernández-Urcera J, Garci ME, González ÁF, Guerra Á, Morales-Nin B. 2014. Using artificial devices for identifying spawning preferences of the European squid: usefulness and limitations. Fish Res. 157:70–77.
Chen CS, Pierce GJ, Wang J, Robin JP, Poulard JC, Pereira J, Zuur AF. 2006. The apparent disappearance of *Loligo forbesi* from the south of its range in the 1990s: trends in *Loligo* spp. abundance in the Northeast Atlantic and possible environmental influences. Fish Res. 78:44–54.
Christensen, JH, Kanikicharla KK, Aldrian E, An S-I, Cavalcanti IFA., de Castro M, Dong W, Goswami P, Hall A, Kanyanga JK, et al. 2013. Climate phenomena and their relevance for future regional climate change. In: Stocker TF, editors. Climate change 2013: The physical science basis. Contribution of working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge: Cambridge University Press; p. 1217–1308. doi: 10.1017/CBO9781107415324.028.
Dash SK, Mishra SK, Pattnayak KC, Manmgain A, Mariotti L, Coppola E, Giorgi F, Giuliani G. 2015. Projected seasonal mean summer monsoon over India and adjoining regions for the twenty-first century. Theor Appl Climatol. 122(3–4):581–593.
Downey N, Roberts MJ, Baird D. 2009. An investigation of the spawning behaviour of the chokka squid *Loligo reynaudii* and the potential effects of temperature using acoustic telemetry. ICES J Mar Sci. 67:231–243.

Fernandez J. 1996. Artificial fish habitats. A community programme for bio-diversity conservation. Artificial reefs and Seafarming technologies. Bull Cent Mar Fish Res. 48:42–55.

Forsythe JW. 1993. A working hypothesis of how seasonal temperature change may impact the field growth of young cephalopods. In: Okutani T, O'Dor RK, Kubodera T, editors. Recent advances in cephalopod fisheries biology. Tokyo: Tokai University Press; p. 133–143.

Goswami BB, Mani NJ, Mukhopadhyay P, Waliser DE, Benedict JJ, Maloney ED, Khairoutdinov M, Goswami BN. 2011. Monsoon intraseasonal oscillations as simulated by the superparameterized Community Atmosphere Model. J Geophys Res. 116. doi:10.1029/2011JD015948

Goswami BN, Venugopal V, Sengupta D, Madhusoodanan M, Xavier PK. 2006. Increasing trend of extreme rain events over India in a warming environment. Science. 314:1442–1445.

Hanson PJ, Vaughan DS, Narayan S. 2006. Forecasting annual harvests of atlantic and gulf menhaden. N Am J Fish Man. 26(3):753–764.

Heiberger RM, Holland B. 2004. Statistical analysis and data display: an intermediate course with examples in S-PLUS, R, and SAS. New York: Springer; p. 729. ISBN 0-387-40270-5.

Iwata Y, Ito K, Sakurai Y. 2010. Is commercial harvesting of spawning aggregations sustainable? The reproductive status of the squid *Loligo bleekeri*. Fish Res. 102:286–290.

Jackson GD, O'Dor RK. 2001. Time, space and the ecophysiology of squid growth, life in the fast lane. Vie Milieu. 51(4):205–215.

Johannessen OM, Subbaraju G, Blindheim J. 1981. Seasonal variations of the oceanographic conditions off the southwest coast of India during 1971–1975. Fisk Dir Skr Ser Hm Unders. 18:247–261.

Kwiatkowski D, Phillips PCB, Schmidt P, Shin Y. 1992. Testing the null hypothesis of stationarity against the alternative of a unit root. J Econom. 54(1–3):159–178.

Lefkaditou E, Sa´Nchez P, Tsangidis A, Adamidou A. 1998. A preliminary investigation on how meteorological changes may affect beach-seine catches of *Loligo vulgaris* in the Thracian Sea (Eastern Mediterranean). Afr J Mar Sci. 20:453–461.

Ljung GM, Box GEP. 1978. On a measure of a lack of fit in time series model. Biometrika. 65(2):297–303.

Martins RS, Perez JAA. 2007. The ecology of loliginid squid in shallow waters around Santa Catarina Island, southern Brazil. Bull Mar Sci. 80:125–146.

Martins RS, Perez JAA, Schettini CAF. 2006. The squid *Loligo plei* around Santa Catarina Island, southern Brazil: ecology and interactions with the coastal oceanographic environment. J Coast Res. 39:1285–1290.

Mohamed KS. 1993. Spawning congregations of Indian squid *Loligo duvauceli* (Cephalopoda Loliginidae) in the Arabian Sea off Mangalore and Malpe. Indian J Mar Sci. 22:172–175.

Mohamed KS, Zacharia PU, Maheswarudu G, Sathianandan TV, Abdussamad EM, Ganga U, Pillai SL, Sobhana KS, Nair RJ, Jose J, et al. 2014. Minimum Legal Size (MLS) of capture to avoid growth overfishing of commercially exploited fish and shellfish species of Kerala. Mar Fish Inf Ser. 220:3–7. T&E Series.

Moreno A, Azevedo M, Pereira J, Pierce GJ. 2007. Growth strategies in the squid *Loligo vulgaris* from Portuguese waters. Mar Biol Res. 3(1):49–59.

Murray FC. 1999. Developmental abnormalities in the cephalopod embryo [BSc Hon. thesis]. University of Aberdeen.

Naidu PD, Kumar MRR, Babu VR. 1999. Time and space variations of monsoonal upwelling along the west and east coasts of India. Cont Shelf Res. 19:559–572.

Pankratz A. 1983. Forecasting with Univariate Box-Jenkins Models: concepts and cases. New York: John Wiley and Sons; p. 576. doi:10.1002/9780470316566

Pecl GT, Jackson GD. 2008. The potential impacts of climate change on inshore squid: biology, ecology and fisheries. Rev Fish Biol Fish. 18:373–385.

Pecl GT, Tracey SR, Semmens JM, Jackson GD. 2006. Use of acoustic telemetry for spatial management of southern calamary Sepioteuthis australis, a highly mobile inshore squid species. Mar Ecol Prog Ser. 328:1–15.

Pierce GJ, Boyle PR. 2003. Empirical modelling of interannual trends in abundance of squid (*Loligo forbesi*) in Scottish waters. Fish Res. 59:305–326.

Pierce GJ, Guerra A. 1994. Stock assessment methods used for cephalopod fisheries. Fish Res. 21:255–285.

Pierce GJ, Valavanis VD, Guerra A, Jereb P, Orsi-Relini L, Bellido JM, Katara I, Piatkowski U, Pereira J, Balguerias E, et al. 2008. A review of cephalopod-environment interactions in European Seas. Hydrobiologia. 612:49–70.

Postuma FA, Gasalla MA. 2010. On the relationship between squids and environmental conditions: the artisanal jigging for *Loligo plei* at São Sebastião Island 24° (S), southeastern Brazil. ICES J Mar Sci. 67(7):1353–1362.

Prell WL, Curry WB. 1981. Faunal and isotopic indexes of monsoonal upwelling-western Arabian Sea. Oceanol Acta. 4:91–98.

R Core Team 2015. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. https://www.R-project.org/.

Roberts MJ. 1998. The influence of the environment on chokka squid *Loligo vulgaris reynaudii* spawning aggregations: steps towards a quantified model. Afr J Mar Sci. 20:267–284.

Roberts MJ. 2005. Chokka squid (*Loligo vulgaris reynaudii*) abundance linked to changes in South Africa's Agulhas Bank ecosystem during spawning and the early life cycle. ICES J Mar Sci. 62:33–55.

Roberts MJ, Sauer WHH. 1994. Environment: the key to understanding the South African chokka squid (*Loligo vulgaris reynaudii*) life-cycle and fishery? Antarct Sci. 6:249–258.

Robin JP, Denis V. 1999. Squid stock fluctuations and water temperature: temporal analysis of English Channel Loliginidae. J Appl Ecol. 36:101–110.

Rodhouse PG, Pierce GJ, Nichols OC, Sauer WH, Arkhipkin AI, Laptikhovsky VV, Lipiński MR, Ramos JE, Gras M, Kidokoro H, et al. 2014. Environmental effects on cephalopod population dynamics: implications for management of fisheries. Adv Mar Biol. 67:99–233.

Rosenberg AA, Kirkwood GP, Crombie JA, Beddington JR. 1990. The assessment of annual stocks of squid species. Fish Res. 8:335–350.

Rowell TW, Young JH, Poulard JC, Robin JP. 1985. Changes in the distribution and biological characteristics of *Illex illecebrosus* on the Scotian shelf, 1980–83. NAFO Sci Coun Stud. 9:11–26.

Roxy MK, Ritika K, Terray P, Murtugudde R, Ashok K, Goswami BN. 2015. Drying of Indian subcontinent by rapid Indian Ocean warming and a weakening land-sea thermal gradient. Nat Commum. 6:7423.

Ryther JH, Hall JR, Please AK, Bakun A, Jones MM. 1966. Primary organic production in relation to the chemistry and hydrography of the western Indian Ocean. Limnol Oceanogr. 11(3):371–380.

Sakurai Y, Kiyofuji H, Saitoh S, Goto T, Hiyama Y. 2000. Changes in inferred spawning areas of *Todarodes pacificus* (Cephalopoda: Ommastrephidae) due to changing environmental conditions. ICES J Mar Sci. 57:24–30.

Sasikumar G, Mohamed KS. 2012. Temporal patterns in cephalopod catches and application of non-equilibrium production model to the cephalopod fishery of Karnataka. Ind J Mar Sci. 41 (2):134–140.

Sauer WHH, Goschen WS, Koorts AS. 1991. A preliminary investigation of the effect of sea temperature fluctuations and wind direction on catches of Chokka squid *Loligo vulgaris reynaudii* off the Eastern Cape, South Africa. Afr J Mar Sci. 11:467–473.

Sauer WHH, Smale MJ, Lipinski MR. 1992. The location of spawning grounds, spawning and schooling behaviour of the squid *Loligo vulgaris reynaudii* (Cephalopoda: Myopsida) off the Eastern Cape Coast, South Africa. Mar Biol. 114:97–107.

Schön PJ, Sauer WHH, Roberts MJ. 2002. Environmental influences on spawning aggregations and jig catches of chokka squid *Loligo vulgaris reynaudii*: a 'black box' approach. Bull Mar Sci. 71 (2):783–800.

Sharmila S, Joseph S, Sahai A, Abhilash S, Chattopadhyay R. 2015. Future projection of Indian summer monsoon variability under climate change scenario: an assessment from CMIP5 climate models. Glob Planet Chang. 124:62–78.

Silas EG, Rao KS, Sarvesan R, Nair KP, Vidyasagar K, Meiyappan MM, Sastry YA, Rao BN. 1985. Some aspects of biology of squids. In: Cephalopod bionomics, fisheries and resources of the EEZ of India., E.G. Silas (Ed.). Bull Cent Mar Fish Res Inst. 37:38–48.

Sims DW, Genner MJ, Southward AJ, Hawkins SJ. 2001. Timing of squid migration reflects North Atlantic climate variability. Proc R Soc London Ser B Biol Scis. 268:2607–2611.

Sooraj KP, Terray P, Mujumdar M. 2014. Global warming and the weakening of the Asian summer Monsoon circulation: assessments from the CMIP5 models. Clim Dyn. 45:1–20.

Srinath M, Kuriakose S, Mini KG. 2005. Methodology for estimation of marine fish landings in India. Cent Mar Fish Res Inst Spl Publ. 86:57.

Turner AG, Annamalai H. 2012. Climate change and the South Asian summer monsoon. Nat Clim Change. 2:587–595.

Wei WWS. 1994. Time series analysis: univariate and multivariate methods. Redwood City (CA): Addison-Wesley; p. 478.

Worms J. 1983. *Loligo vulgaris*. In: Boyle PR, editor. Cephalopod life cycles vol. I: species accounts. London: Academic Press; p. 143–157.