Turk. J. Fish.& Aquat. Sci. 20(4), 267-278
http://doi.org/10.4194/1303-2712-v20_4_03

RESEARCH PAPER

Turkish Journal of FISHERIES and AQUATIC SCIENCES

Fishery and GIS Based Spatio-Temporal Distribution Analysis of Smooth Blaasop, *Lagocephalus inermis*, in South-Eastern Arabian Sea

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Article History
Received 28 August 2018
Accepted 13 May 2019
First Online 17 May 2019

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Keywords
GIS tools
Spatial indicators
Abundance
Trophic cascading
Ecosystem management

Abstract

Investigations on distribution of species on a spatio-temporal scale has ecological and management significance. Study was carried out in one of the productive zones of south eastern Arabian sea on *Lagocephalus inermis* one of the emerging fishery resource from 2015 to 2017 in comparison with 2008. GIS tools was used to support fishery analysis, abundance and distribution of species. Average catch for 2015-17 period was 3456 t which showed twelve fold increase compared to 2008. Spatial and temporal analysis of the abundance of species showed a range from 7-277 kg/hr (Catch Per Hour) at a depth range of 20-100 m. Juveniles were observed more towards near shore area with aggregation in clayey region. Spatial indicators (spatial dispersion, directional dispersion and directional trend) were calculated by year. Spatial distribution value was highest in 2016 indicating a wider distribution of *L. inermis*, whereas this distribution was more compact in 2008. It was also observed that in 2008 the central tendency is located in the Southern-most part of the study area whereas during recent period shifted to the Northern side. Species associated with *L. inermis* were all mid- level carnivores similar to the species indicating a trophic cascading happening in the Arabian Sea.

Introduction

Puffer fishes (Family: Tetraodontidae) which are also popularly known as blowfishes, globe fishes, balloon fishes and toad fishes, are so called due to the presence of four (*tetra*) teeth-like structure in their mouth. Tetraodontidae is a marine fish family that has about 19 genera and 130 valid species which are mostly shallow and demersal water inhabitants of tropical/subtropical region of the marine environments, with several species entering and occurring in brackish and freshwater environments as well (Nelson, 2006; Froese & Pauly, 2007; 2013).

The members of this family are particularly famous for the presence of a specific toxin called tetrodotoxin which is responsible for the death of many gastronomers each year. However, they are being exploited throughout the world and the fishery is slowly growing. Average global production of puffer fish from the year 2013-16 was estimated to be 35,962 t (FAO Fish Statistics, 2018). About 95% of the production was from Asia since it is a delicacy in many South-East Asian countries.

Smooth blaasop, *Lagocephalus inermis,* (Figure 1) is a member of this family and is widely distributed in the depth range of 10-200 m in the Indo-West Pacific region from Algoa Bay, South Africa to the coasts of the Yellow Sea, East China Sea, South China Sea, and Taiwan (Su & Li, 2002) and in the Western & Eastern Indian Ocean (Mahapatra & Pradhan, 2016). Studies on growth

Published by Central Fisheries Research Institute (SUMAE) Trabzon, Turkey in cooperation with Japan International Cooperation Agency (JICA), Japan

Figure 1. A specimen of *Lagocephalus inermis*

pattern, food and feeding, reproductive biology and toxicity of other species of the same genus has been carried out (Sabrah, El-Ganainy & Zaky 2006; Aydin, 2011; Saoudi *et al.*, 2011; Nagashima, Matsumoto, Kadoyama, Ishizaki & Terayama, 2011; Nader, Indary & Boustany, 2012; Mandal, Jal, Mohanapriya & Khora, 2013; Kalogirou, 2013). The occurrence of the species is reported from different parts of India (Doiphode, 1985; Talwar & Jhingran, 1991; Kapoor, Dayal & Ponniah 2002; Rajan, Sreeraj & Immanuel, 2011; Veeruraj, Muthuvel, Ajithkumar & Balasubramanian, 2011; Dineshbabu, Thomas & Radhakrishnan, 2012; Venkataraman, Rajkumar, Satyanarayana, Raghunathan & Venkatraman, 2012) but the distribution and fishery of the species is not studied in this region. Thorough study of literatures revealed very little information about the fishery in India as this did not have much value and was considered as menace by the fishermen (Thomas, Kemparaju & Sampathkumar, 2007; Mohamed, Sathianandan, Kripa & Zacharia, 2013). The emergence of this resource has been attributed as a sign of the beginning of a trophic cascading and signals of predation induced top-down effect on the mid-level carnivore population in the Arabian Sea and fishing down the web (Vivekanandan, Srinath & Kuriakose, 2005). The resource has slowly grown as an economically valuable one and is emerging as a new fishery along the coast of Karnataka (Thomas *et al.*, 2007). It is now exploited in large quantities along south-eastern Arabian Sea and is consumed in fresh and dry condition.

Fish distribution and abundance varies across spatial scale and elucidating the variations on a spatio-temporal scale has ecological and management significance (Ciannelli, Fauchald, Chan, Augustine & Dingsør, 2008). The study on the distribution and fishery is a prerequisite for conservation and ecosystem-based management. It is also widely accepted that pressures on the marine resources are often excessive and efforts are to be taken to minimize the negative impact on the resources and marine environment (Barnes & Metcalfe, 2010). In addition to this, the species are expected to respond to change in climate by shifting their distribution range (Alagador, Cerdeira & Araujo, 2016).

Lack of knowledge on the abundance and distribution of a species would not only curb our understanding of the ecological processes but also affect management plans for conservation (Maitland, 1995). Hence a study to analyze the fishery, abundance and distribution of the *L. inermis* on a GIS platform was carried out in one of the productive zones in south-eastern Arabian Sea. Comparison of the distribution and abundance of the species during 2008-09 and 2015-17 was also done to elucidate changes in distribution pattern, if any, for the species. The study focused on the emerging puffer fish fishery along the Indian coast, and is first of its kind in the south-eastern Arabian Sea describing the distribution of this species on a GIS platform incorporating the grounds of adult and juveniles and the relationship with sediment texture although Mahapatra & Pradhan (2016) has reported the occurrence of the species from elsewhere in the country.

Materials and Methods

Study Area

The study area is located in south-eastern Arabian Sea extending from Calicut in Kerala to Thane in Maharashtra with GPS location 11.969°N 71.794°E to 18.821°N 74.932°E (Figure 2). This area represents the trawling grounds in the region which extends up to 200 m depth latitudinal. The fishing was done from 20-200 m depth.

Collection of Data

The data was collected from 2015 to 2017 by using two methods which are described below. Pattern of distribution in 2015 to 2017 was compared with the distribution in 2008 to 09. The study area was calculated from shapefile created in Geo database.

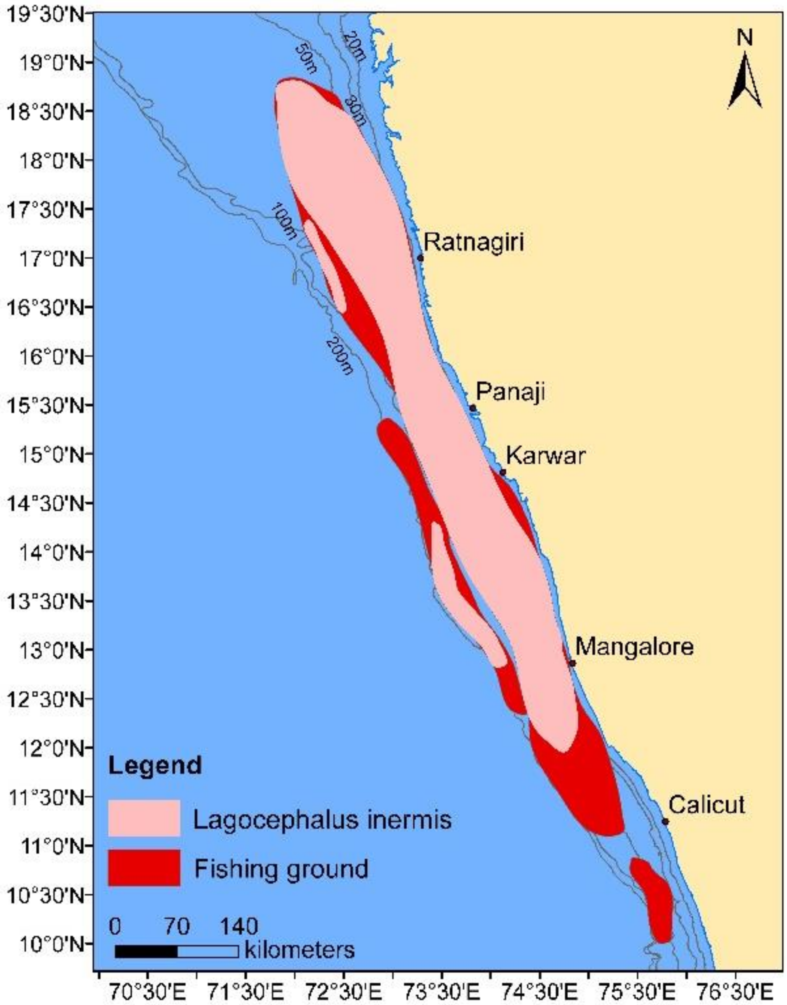

Figure 2. Map depicting the trawling ground along the south-eastern Arabian Sea.

Fishery Data

The sampling design adopted for the study to estimate landings is based on stratified multi-stage random sampling technique. In this method, stratification takes place over space and time. Over space, the south-eastern Arabian Sea is stratified into suitable, non-overlapping zones on the basis of fishing intensity and geographical considerations (Srinath, Kuriakose & Mini, 2005). Weekly catch data (in Kg) was collected from pre-identified commercial trawlers all along the study area. The LO_A of trawlers was 15.85 m with 160 hp engine which were engaged in multi-day trawling operating from 20-200 m depth for 8-13 d. The present data was compared with the previous year catches from 2007 to 2014 (National Marine Fisheries Data Centre (NMFDC), Central Marine Fisheries Research Institute (CFMRI).

Onboard Data Collection

Crew in the sampling vessel was trained for onboard data collection using a customized log sheet. The database included speed of the boat, no of days of fishing, date, geographic location, shooting and hauling depth, time of shooting and hauling, number of haul, net type, mesh size, total haul, total catch and discard and species composition (Dineshbabu, Thomas & Dinesh, 2016). The samples were preserved in ice, stored in the fish-hold and brought to the laboratory for further analysis. Total length (TL) to the nearest cm and sex of each individual was recorded.

Sediment Texture Data

The sediment distribution map used was from Hashimi, Nair and Kidwai (1978); Rao and Wagle (1997), which was later digitized and geo-referenced in ArcGIS. Three types of sediment textures were taken into consideration namely clayey, terrigeneous sands and carbonate sands.

Data Filtration

As the logbook given to the fishermen contained information about all the associated species as well, only the data of *L. inermis* was extracted for the study. Data was filtered based on catch estimates and total fishing hours for calculating the Catch Per Hour (CPH). The associated fish species were also identified (Fischer & Bianchi, 1984). The adults were delineated from the juveniles based on minimum size at maturity (MSM) from the information obtained from biological analysis.

Data Analysis

Fishery

Fishery status during end of study period was calculated based on difference in catch percentage from the initial year of study. The monthly and yearly contribution of *L. inermis* landings from the multi-day trawlers for the study period is accounted since it was found that these were the major gears used for the fishing. To study the abundance of the species, Catch Per Hour (CPH) was estimated. The CPH was calculated using the following formula:

$$\text{Catch Per Hour} = \frac{\text{C total}}{\text{H total}}$$

Where C_{total} is total catch in Kg and H_{total} is total fishing hours.

For processing, analyzing and for easy access of the data, coded fields and keywords were incorporated into the database FRIMS (Fisheries Resource Information Management System), a software developed based on Visual Basic 6.0, to aid smooth handling of the data (Dineshbabu *et al.*, 2016). FRIMS helped in sending simple and complex queries and extract the required data for the study and to plot the results on the map.

Measuring Geographic Abundance Distribution

Quantitative multi-parameter modeling through GIS tools was done and the spatial data was processed using ArcGIS 10.2 ESRI. Spatial indicators of central tendency, spatial dispersion, directional dispersion and directional trends was calculated using "Measuring Geographic Distribution" toolset in spatial statistical toolbox of ArcGIS 10.2 (Perzia, Battaglia, Consoli, Andaloro & Romeo, 2016) to summarize the spatial and temporal distribution of smooth blaasop.

Central tendency which is a measure of geographic center of the smooth blaasop distribution was calculated by the "mean center" tool in ArcGIS. This is calculated as the average x and y geographical coordinates of all catches recorded is the study area. Variation in the central tendency reflects variation in distribution over time and/or space and was calculated for each year.

The spatial dispersion represents the degree to which the catches are spatially concentrated or spatially dispersed around the geometric mean center. The spatial dispersion is represented by a circle of radius equal to a value containing 95% of catches. Spatial dispersion was calculated for each year.

Directional dispersion measures the standard distance of point separately in x- and y- directions and it represents 95% of the catches. Directional trend indicates in which direction the trend extends. The directional dispersion and directional trend values were calculated using "Standard Deviational Ellipses" (SDE) tools in ArcGIS and it was mapped for each year. The methodology flow chart is given in Figure 3.

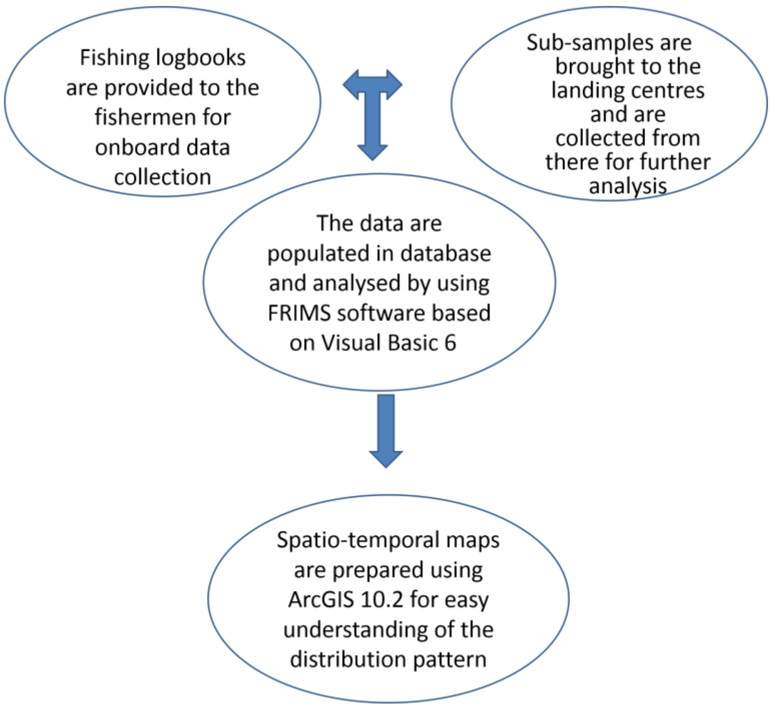

Figure 3. Flow Chart of Methodology.

Result

Fishery

Fishes were caught mainly by trawlers operating in the depth range of 20-200m for 8-13 days fishing. The average catch over the study period (2015-17) was 3456 t. The maximum catch was in the year 2015 which amounted to approximately 5111 t. However, it was found that there was a sudden decline in catch in the year 2016, touching a low of approximately 2067 t. In the year 2017 the fishery again started to increase and a total catch of approximately 3189 t was estimated. The catch in the study period compared with the trend in catches from 2007 to 2017 is given in Figure 4. The catch was as low as 488 t when the fishery commenced and peak was observed in 2012. There was sudden decline in catch during preceding years and after 2016 there is again an increasing trend.

The CPH ranged between 1.04 and 1.35 kg, with maximum in 2015 and minimum in 2016 (Figure 5). The average month-wise abundance analysis of *L inermis* for 2015-17 period revealed that it is most abundant in May (Pre-monsoon) and minimum in late August (Monsoon) (Figure 6).

Associated Fish Communities

A total of 20 species were found associated with this species in the same ground during the study period. Out of this 14 were fin-fishes, 4 crustaceans and 2 molluscs. The major fin-fish and shell-fish species are listed in Table 1.

Distribution

To understand the distribution of *L. inermis* along the south-eastern coast of Arabian Sea 670 fishing day's

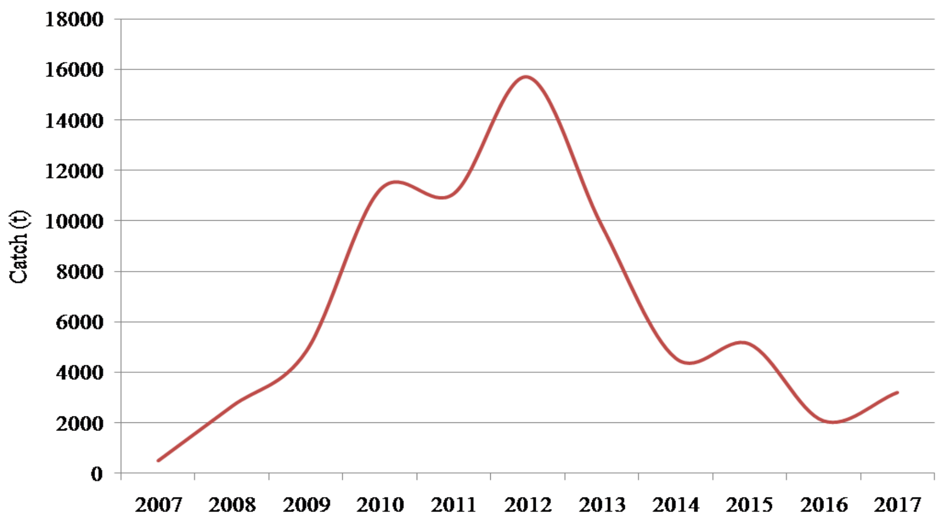

Figure 4. Estimated Catch of *Lagocephalus inermis* along south-eastern Arabian Sea (2007-2017).

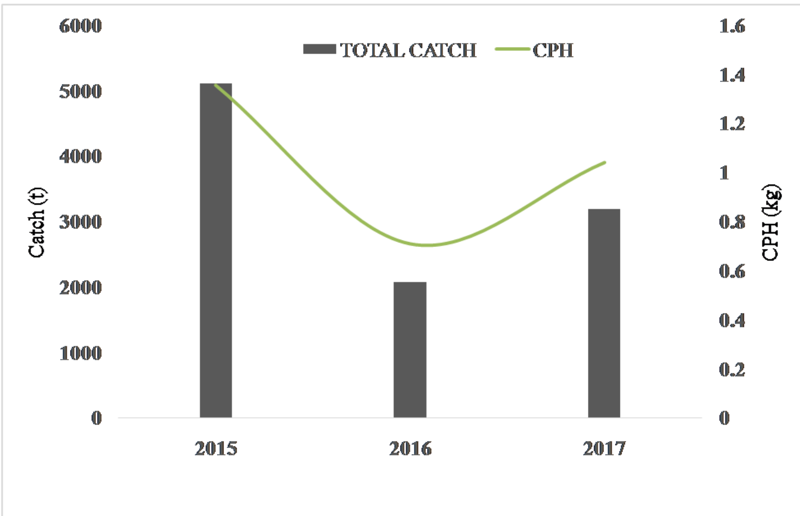

Figure 5. Estimated total catch(t) (in tonnes) and CPH (kg) of *L. inermis* for the study period

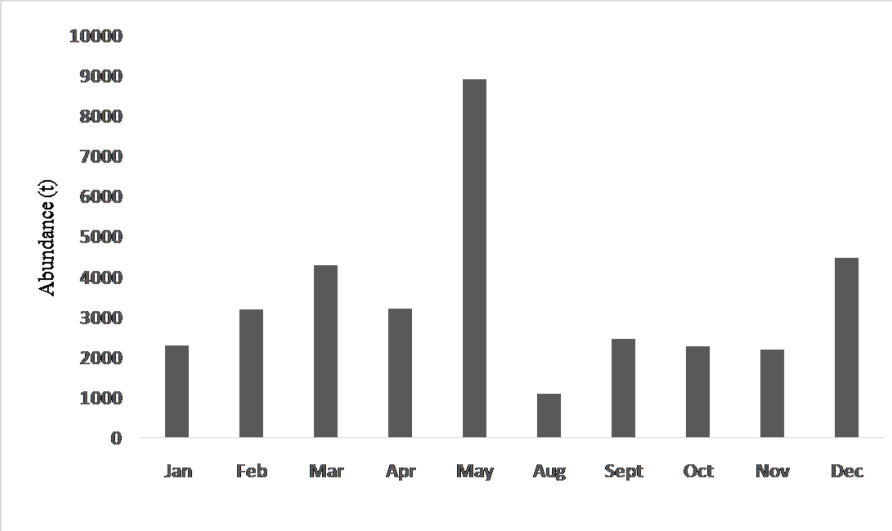

Figure 6. Estimated abundance value (in tonnes) of *L. inermis* for all the years (2015-17) on a monthly basis.

Table 1. List of prey items in the gut content of *Lagocephalus inermis*

Finfishes	Shellfishes
Decapterus russelli	*Charybdis feriatus*
Epinepelus diacanthus	*C. smithi*
Lactarius lactarius	*C. hoplites*
Leiognathus spp.	*Parapaenopsis stylifera*
Megalaspis cordyla	*Loligo* spp.
Nemipterus japonicus	*Sepia* spp.
N. randalli	
Priacanthus hamrur	
Rastrelliger kanagurta	
Saurida tumbil	
S. undosquamis	
Scomberomorus commerson	
Sphyraena spp.	
Trichiurus lepturus	

data were analyzed. The fishes were mostly found in the depth range of 20-100 m with patchy distribution in 200 m. (Figure 7). The total study area was estimated at 76316 sq. km. About 30% of the area was occupied by *L. inermis* in 2008 while in the 2015 to 17 the area of distribution increased to 77%. The total trawling ground extended between10.05°E 71.799°N to 18.888°E 75.876°N. Maximum fishing pressure for the species was found in the depth range of 20-100 m.

Abundance of the Species

The spatial and temporal analysis of the abundance of the species in the study area showed a range from 7-277 kg/hr (CPH). Maximum CPH was observed in May, 2016 and lowest value was in early September, 2017. The abundance of the species in the fishing area is given in Figure 8. It is observed that the maximum was in the depth range of 60-80 m in the geographical location of 18.83324°N and 71.94872°E.

Ontogenetic Distributional Pattern

The size of the species ranged from 7.5-54.5 cm. The minimum size at maturity (MSM) was found to be 18.3 cm. The specimens below MSM were considered to be juveniles for the present study. The juveniles were observed throughout the fishing area in the near shore waters in the depth range of 20-80 m however the adults were found in all the depth ranges. They were more extensive in distribution as compared to the adult grounds (Figure 9).

Distribution Pattern in Relation to Sediment Texture

Three types of sediment textures were observed in the study area namely clay, carbonate sands and terrigeneous sands. The distribution of the species was observed to be more aggregated in the clayey region (Figure 10).

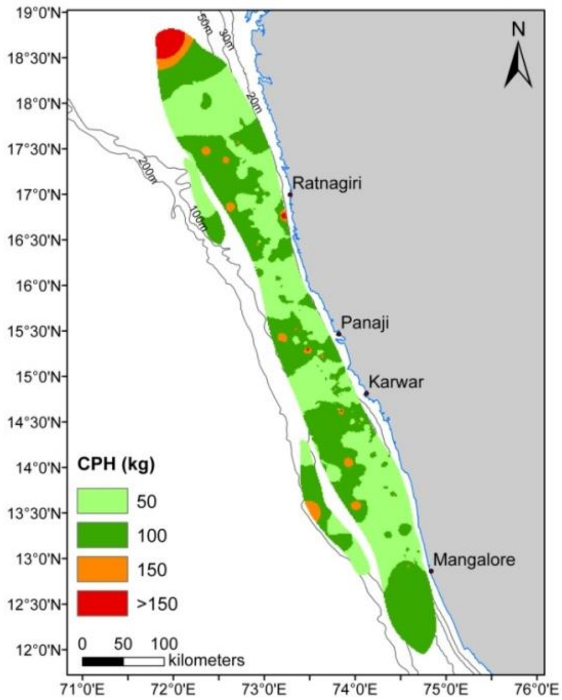

Figure 8. Abundance Map of *L. inermis* along south-eastern Arabian Sea.

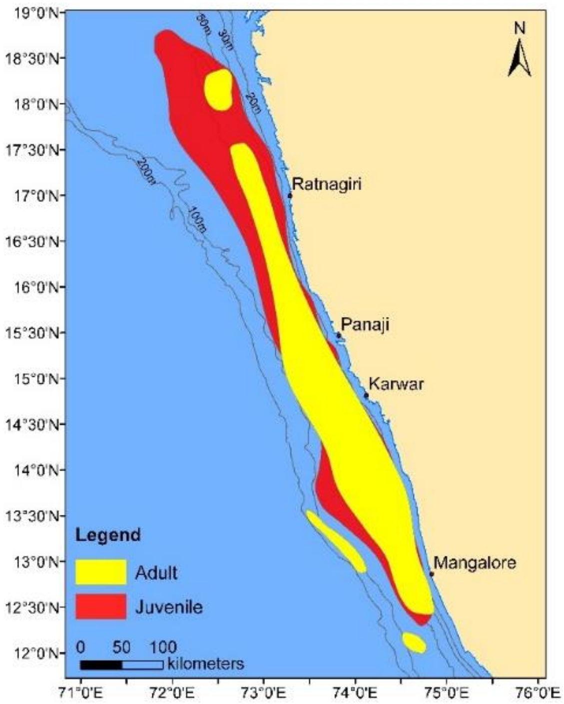

Figure 9. Distribution of adult and juvenile grounds of *L. inermis.*

Measuring Geographic *L. inermis* Distribution

The spatial indicators (spatial dispersion, directional dispersion and directional trend) calculated by year are given in Table 2. The spatial distribution value was highest in 2016 indicating a wider distribution of *L. inermis* in the study area, whereas this distribution was more compact in 2008. Similar trend was observed by the indicator Directional Dispersion in the same year of x-value. The dispersion along the y-axis resulted lower in 2015. Geographical orientation ranged between 156-161° for directional trend of distribution of annual catches (Table 2).

Abundance from 2008 and 2015-17 together with the representation of spatial indicators such as spatial dispersion, directional dispersion and directional trends

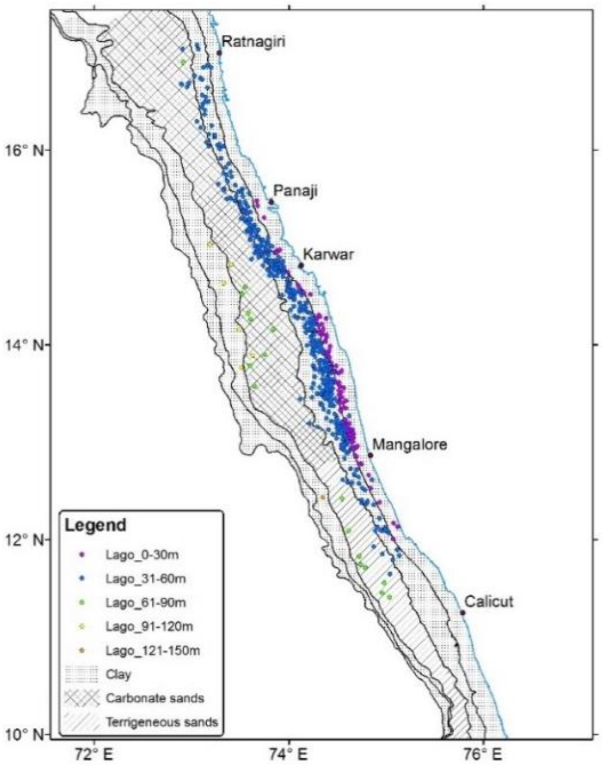

Figure 10. Spatial distribution of *L. inermis* along the coast based on sediment texture.

Table 2. Values of the spatial indicators Spatial Dispersion, Directional Dispersion, Directional Trends by year

Data Aggregation	Spatial Distribution (m)	Directional dispersion x (m)	Directional dispersion y (m)	Directional trend (°)
2008	111292	155998	20894	161.0
2015	177672	250392	20942	157.9
2016	180768	254183	27293	157.8
2017	143822	202347	20616	156.0

are given in Figure 11. The widest distribution of *L. inermis* catches was recorded during 2016 in the study area whereas they were more concentrated in 2017. During 2008 the species had a limited distribution in the study area.

The central tendency of catch distribution for the study period 2008 and 2015-17 is depicted in Figure 12. It is observed that the central tendency is located in the southern-most part of the study area whereas during the recent period (2015-17) it had shifted to the northern side.

Discussion

L. inermis has become an emerging resource in south-eastern Arabian Sea since 2007 (Thomas *et al.*, 2007) and an increasing trend in catch is observed since then. There was fluctuation in catch over the period and at present the catch is increasing when compared to previous year. As a result of demand in the market it became a targeted fishery and its economic value increased substantially. The market value has increased five folds when compared to the year when fishery started (Thomas *et al.*, 2007). The fish which was costing INR 8/kg during 2007 has increased to INR 40-50/kg in 2017. The fish is known for its toxicity but still it is degutted, skin peeled off and marketed in fresh and dried forms (Figure 13). There is lack of information on the fishery of this species globally and hence this study will be a pioneering attempt to fill this knowledge gap.

The emerging fishery of the species is an indicator of fishing down the web (Bhathal & Pauly, 2008). The studies along the region had indicated decrease in mean trophic level due to increasing fishing effort the removal of high trophic level predator have resulted in emerging of mid-level carnivores like *L. inermis* (Vivekanandan *et al.*, 2005). A pattern of trophic cascading in the Arabian Sea could be observed from 2007 which has resulted in increasing the biomass of puffer fish. Trophic cascading is defined as an ecological phenomenon triggered by the addition or removal of top predators and involving reciprocal changes in the relative populations of

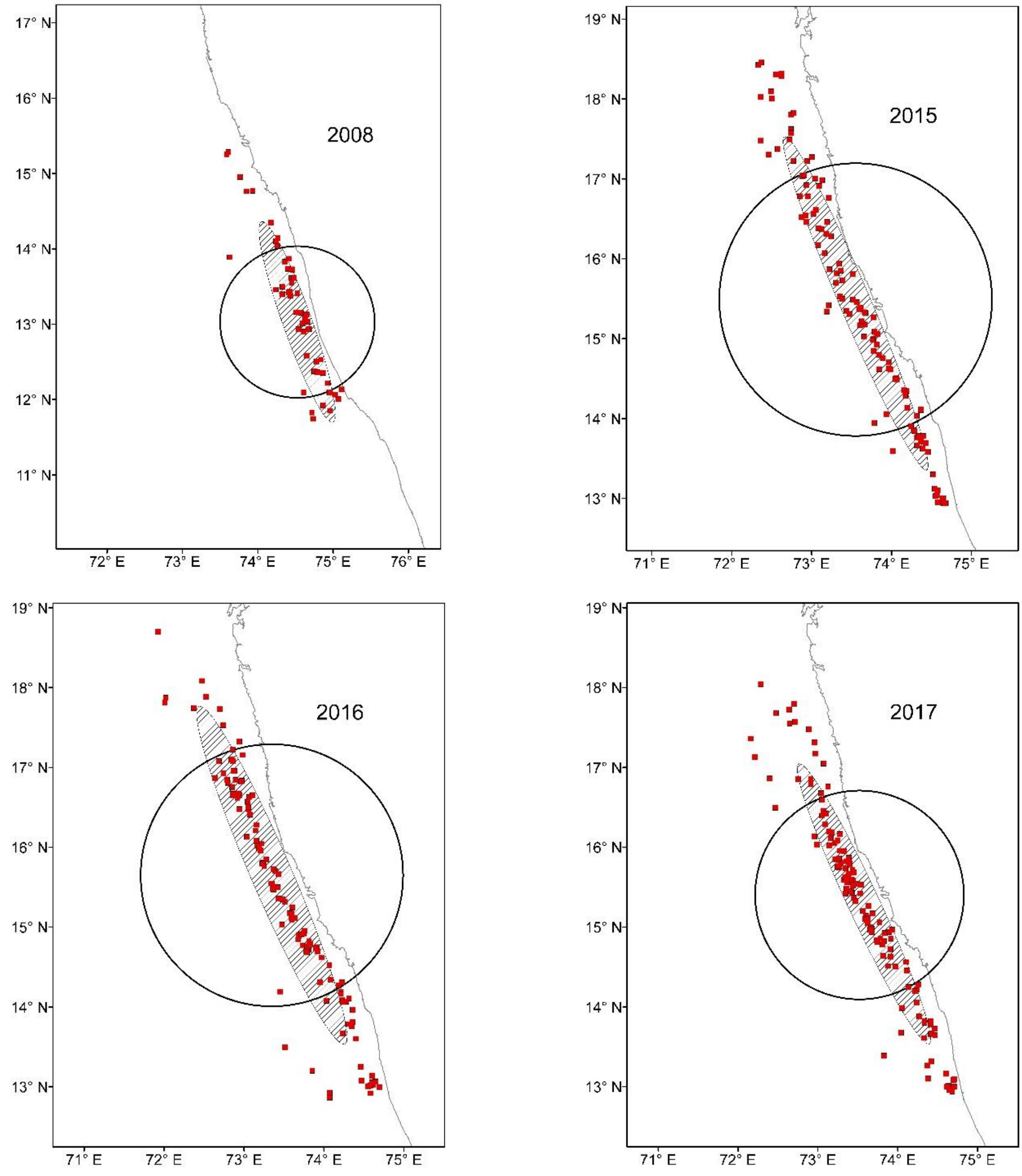

Figure 11. Monthly maps of *L. inermis* caught from 2015 to 2017 and 2008. Directional Dispersion and Trends and Spatial Dispersion for all catches (black circle) are shown.

predator and prey through a food chain which often resulted in dramatic changes in ecosystem structure. In this case there are signals of predation induced top-down effect on the mid-level carnivore population in the Arabian Sea (Mohamed *et al.*, 2013). In the present study also fish groups that dominated along with *L. inermis* were mostly mid-level carnivores which could be an indicator of trophic cascading. For trophic cascading studies, monitoring of the changes in biomass and abundance of the species in the ecosystem has to be done. The present investigation on the abundance of *L. inermis* and the associated communities would help in strengthening the database for ecosystem-based management.

The present fishery has shown a six fold increase when compared to 2006-07 (Thomas *et al.*, 2007). The estimated catch during 2007 when the fishery started was 488 t while that in 2015-17 is 3456 t. The peak landing was observed in 2015 during the study period (2015 to 2017) when the other commercial species showed a decreasing trend (CMFRI, 2016). The abundance of the species showed a fluctuating trend over the months in that peak abundance was found during pre-monsoon period. The maximum CPH observed was during pre-monsoon season when the adult population was high in the depth range of 60-80 m.

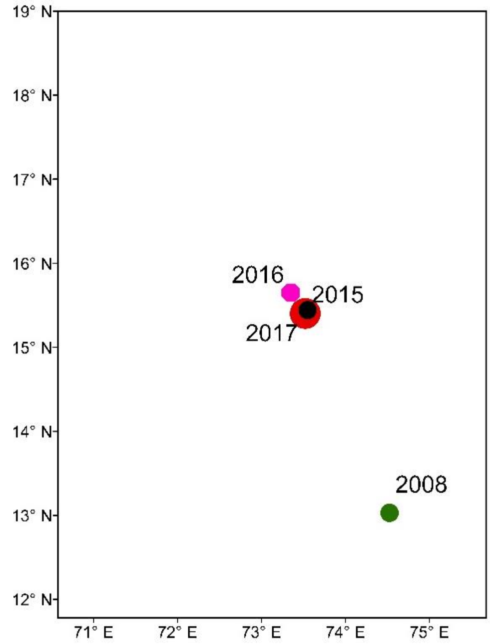

Figure 12. Center of species concentration (Central Tendency indicator) of the *L. inermis* catches per year, from 2015 to 2017 (black, red and pink point) and green point depicts that of 2008.

Figure 13. The viscera, skin and fins of *Lagocephalus inermis* being removed in the landing centre by local fisherwomen.

The distribution of the species in the region is often associated with other similar mid-level carnivores like threadfin breams. The fishes are mostly seen with the depth range of 30-100 m and the juveniles are often observed more towards the near shore areas. Occurrence of juveniles in the near shore areas are also observed in other fishes (Clarke, 1971; Nicholas, Richard, Pylekim, Holland & Barcz, 2012). Along the south-eastern Arabian Sea the near shore waters are more productive especially soon after the upwelling. The aggregation of the juveniles to the near shore water could be attributed to the increase in productivity, which is congenial for growth of juveniles.

The spatial dispersion of the fishes indicates that it is not a homogenous distribution and aggregation of the species is observed in certain areas which could be attributed to the abundance of prey items in the area. The shift in the mean center from 2008 to the recent period also indicates changes in the abundance and distributional pattern over a decade. The reason for the shift is not well understood, however it could be related to the combination of biotic and abiotic factors influencing the species. The use of “measuring geographical distribution” toolset of ArcGIS helped in tracking changes of distribution over time and space producing annual maps representing spatial dispersion, directional dispersion and trends. The comparison of the maps from 2008 and the present period showed a significant difference in distribution of *L. inermis* in the study area.

The observed affinity of the species towards the clayey substratum could not be defined in the present study but further studies in relation to environmental variables and the inter- and intra-specific interactions would throw more light on the variation in the distributional patterns in the ecosystem. This study not only helps in understanding the fishery and abundance of the species but also highlights the potentiality of Geographic Information Systems (GIS) in supporting spatial and temporal analysis of the fishery data. Application and usefulness of GIS in fishery has been already underlined by other authors in regard to resource mapping and spatio-temporal analysis (Riolo, 2006; Close & Hall, 2006; Dineshbabu, Thomas & Radhakrishnan, 2012; Dineshbabu, Thomas & Rohit, 2014; Thomas, Dineshbabu & Sasikumar, 2014; Dineshbabu, Thomas & Shailaja, 2017). The analysis of fishery, abundance and distribution of the species with GIS tools is a powerful mean to understand the distribution of the species in south–eastern Arabian Sea which could be a precursor for the assessment of the stock in the region. The same methodology could be adopted for other fishery resources and analyze the species interactions and species shift in marine ecosystem which could be caused by anthropogenic activities or climate change. Fishery and spatio-temporal distribution analysis of *L. inermis* is one of the important step for ecosystem based management in the region.

Conclusion

The present study on the *L. inermis* is an attempt to analyze the distribution and abundance of this emerging resource. The study has also helped in identification of the adult and juvenile grounds of the species. The fishing pressure has increased over the years and many species have emerged and disappeared from the fishery. *L. inermis* is one of the species that has emerged into dominance with the fishing pressure resulting in trophic cascading happening in the Arabian Sea. This is bound to continue with the existing fishing pressure and more changes are likely happen in the ecosystem. The domination of ecological group could also change resulting in changes in the ecosystem balance. In this scenario the study of distribution and abundance of the emerging fishery resources are important to understand the fishing pressure in terms of ecological perspective. This is the first attempt of its kind and would support the ecosystem-based management of resources in the region.

Acknowledgement

The authors are grateful to the Dr. A. Gopalakrishnan, Director, ICAR-CMFRI, Dr. P.U. Zacharia, Principal Scientist and Head, Demersal Fisheries Division for their constant support and encouragement. The authors would like to acknowledge the funding received from NICRA, ICAR. Authors would like to acknowledge the help rendered by all fishermen who has helped in collecting the data and technical assistants of Mangalore RC of CMFRI who helped in the analysis. First author would like to express her gratitude to Department of Biosciences, Mangalore University, Mangaluru for permitting to do the research work.

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