Spatial Distribution of Marine Fish Landings through a Modified Grid Framework

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Abstract

India has one of the most extensive and diverse marine fisheries sectors in the world, contributing significantly to national food security, employment, and coastal livelihoods. With an Exclusive Economic Zone (EEZ) of 2.02 million square kilometers and India's marine fisheries have great ecological and commercial potential. India's marine capture fisheries are composed of a rich diversity of species—over 2,000 species, and is supported by a multi-gear, multi-species fishery system using mechanized, motorized, and traditional non-motorized crafts. India's marine fish production in recent years has averaged over 4 million tonnes annually, making it one of the top marine fish-producing countries globally. A large portion of the catch is exported, generating substantial foreign exchange revenue. Fishers use different fishing grounds in different seasons depending on fishing opportunities, fish prices, fishing costs, fishing traditions, and/or regulations in force and, therefore, exploit different species and age classes of the population. Spatial mapping of fish landings is vital for visualizing the spatial distribution of fish catches thereby identifying resource use patterns. The mapping process entails gathering geo-referenced data incorporating details such as species caught, quantity landed, and fishing effort. This georeferenced marine fish landings data from major fishing harbours along the southwest coast of India is sourced from National Marine Fisheries Data Centre of ICAR- Central Marine Fisheries Research Institute. Geographic Information Systems (GIS) tools were used to create grid identification codes in which fishing operations were carried out. The coastal waters up to a distance of 50 km from the Southwest coast was divided into 0.25^{o} x 0.25^{o} grids and this forms the basic mapping unit of fishing grounds. The information on the average depth of each of the 0.25^{o} x 0.25^{o} grids was extracted and added to the grid layer. The spatial patterns can aid to prioritize monitoring, assess fishing pressure, and develop region-specific management plans. It also aids in detecting spatial shifts in fish landing patterns caused by factors such as overfishing, climate change, or environmental degradation. This approach supports better fisheries management towards sustainable exploitation of fishery resources.

Keywords: Spatial distribution, fisheries management, Geo-referencing, sustainability,

Introduction

The marine fisheries sector in India plays a vital role in strengthening the national economy by enhancing food and nutritional security, providing livelihoods, and creating employment opportunities. India's Exclusive Economic Zone (EEZ), covering 2.02 million square kilometers, is complemented by an extensive coastline of approximately 11,099 km along its eastern and western coasts. This vast expanse is characterized by rich and diverse marine biodiversity, supported by a continental shelf area of 0.53 million square kilometers (DoF,2025). Over the past two decades, India's fisheries sector has undergone remarkable growth and transformation, driven by technological advancements and policy reforms that have strengthened the country's position in global fisheries and aquaculture. The government has introduced several schemes to support the growth of the fisheries sector, such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY), which aims to increase fish production, improve livelihood of fisherfolk, infrastructure facilities and promote sustainable fishing practices.

Rich in marine biodiversity and home to nearly 2,000 species, India is now the second-largest fish-producing country in the world, contributing about 8 percent of global fish production. In 2024, the country recorded an estimated 3.45 million tonnes of marine fish dominated by species such as sardines, mackerel, ribbonfish, tunas, croakers, shrimps, and cephalopods. Tuna species, in particular, are widely distributed along the Indian coastline, with nearly 50% of the landings occurring along the southwest coast. However, the fisheries sector in India operates in a complex spatial and seasonal environment. Fishers target a variety of species and age classes based on seasonal variations in fish availability, market prices, operational costs, and traditional practices. The increasing expansion of fishing operations into deeper waters, coupled with the shift from single-day to multi-day fishing trips, has made it imperative to incorporate spatial dimensions into fisheries management. Understanding the patterns and drivers of resource exploitation is key to ensuring sustainable fishery practices, and this requires accurate and detailed spatial data to support informed decision-making. (Dineshbabu, *et. al.,* 2019, Padua *et. al*., 2021)

As India's fisheries sector continues to expand, integrating spatial information into fish landing data becomes increasingly essential for effective management of marine resources. The geographic distribution of fishing efforts, along with the seasonal and spatial dynamics of fish stocks, plays a pivotal role in sustainable fisheries management. With fishing grounds shifting into deeper waters, traditional management approaches are proving inadequate. There is a growing need for data that not only identifies the spatial distribution of fish landings but also offers insights into fishing effort patterns and resource utilization (Mohamed *et.al*, 2018). In this context, the present study is carried out to passively geo-reference the fishing grounds of tuna resources landed along the southwest coast of India by incorporating a spatial dimension into landing data. Maps were generated to visualize the distribution of major tuna species, with particular emphasis on landings from the Cochin and Needakara fishing harbours, both located in southwest coast of India.

METHODS

Study Area

The tuna landings along the southwest coast of India in 2024 were collected from the region between 8°-15° N and 65°-78° E (Fig. 1). The study area, which includes 290 fish landing centres, was divided into 33 non-overlapping fishing zones based on fishing intensity and geographical considerations. The number of landing centres varies across these fishing zones

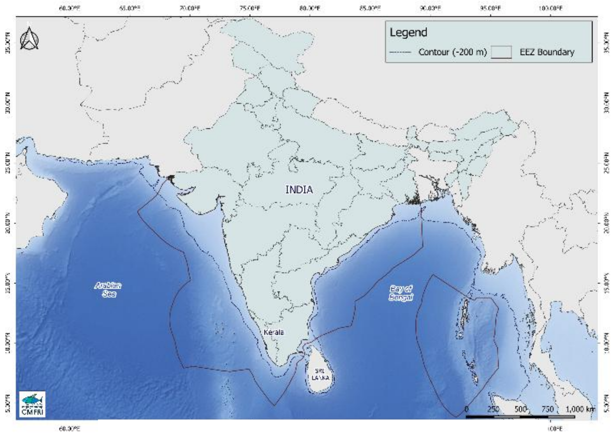

Fig.1 Map showing the study area

Data collection procedure

The field observer visited the study area according to a schedule generated under the stratified multistage random sampling scheme (Srinath et al., 2005), during which tuna landings from various fishing gears were recorded. Additionally, the observer collected data from fishers regarding the distance, direction, and depth of their fishing operations relative to the landing centre. A total of 2,794 observations were made in 2024. During periods of high landing activity, it was often impractical to enumerate catches from every individual boat due to operational constraints, time limitations, and resource availability. In such instances, a sampling procedure was implemented to select a representative subset of boats (Srinath et al., 2005). The data collection and estimation, the Fish Catch Survey and Analysis (FCSA) web-based and mobile application, developed by ICAR-CMFRI, was employed. This system enabled the online transmission of data and landings estimation, utilizing portable electronic tablets/mobile phones to facilitate efficient data entry, processing, and analysis (Mini *et al.*, 2023). Time series data on landings of tuna resources were accessed from MarineSTAT database of ICAR-CMFRI's National Marine Fisheries Data Centre (NMFDC) (ICAR-CMFRI, 2025b).

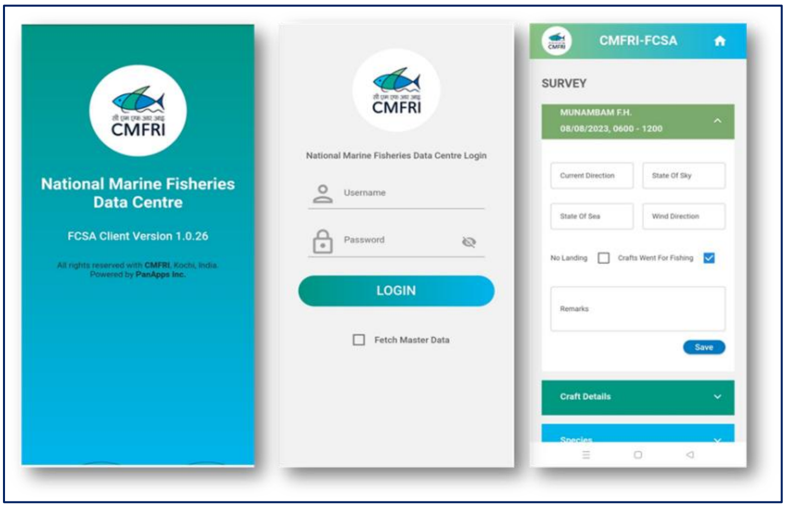

Fig.2 FCSA mobile application

Passive Georeferencing

Passive geo-referencing is a technique in spatial data analysis where geographic coordinates of a location or feature are determined without using direct or active measurement systems like GPS or surveying equipment. The information collected from the surveyed fishing crafts contain essential information such as the direction and the distance covered during each fishing operation. These two parameters, when combined with the known geographic coordinates of the landing centre (starting point), can be used to estimate the probable fishing location. To achieve this, the Haversine formula is applied, which enables the calculation of destination coordinates (latitude and longitude) based on the distance and bearing from a known starting point (Jayasankar *et al*, 2020, Varghese *et al*, 2023).

The probable latitude and longitude of fishing grounds was derived for each landed craft using the following formula.

$\phi 2 = \mathrm{asin}(\sin \phi 1 \cdot \cos \delta + \cos \phi 1 \cdot \sin \delta \cdot \cos \theta)$

$\lambda 2 = \lambda 1 + \mathrm{atan2}\,(\sin \theta \cdot \sin \delta \cdot \cos \phi 1 , \cos \delta - \sin \phi 1 \cdot \sin \phi 2)$

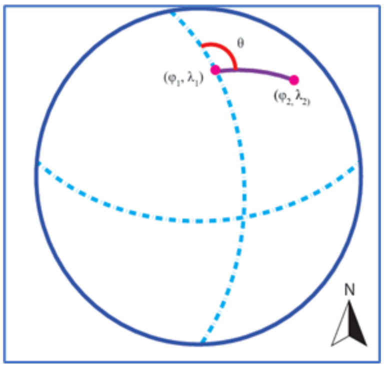

Fig.3 Latitude and Longitude calculation using the bearing and angular distance

where ϕ is latitude, λ is longitude, θ is the bearing (clockwise from north), δ is the angular distance d/R; d being the distance to destination, R the earth's radius (mean radius = 6,371km), 'asin' is arcsine (i.e. the inverse sine) of a given number and 'atan2' is the arctangent (or inverse tangent) of the specified x- and y-coordinates. By implementing this approach, each fishing trip can be geo-referenced to an approximate fishing ground location.

Spatial Mapping

The software used for the analysis were QGIS 3.28.4, R 4.2.2 and MS Excel. The area inside the EEZ was divided into 0.25 x 0.25-degree grids and each grid was given a unique ID. The grid thus generated was used to do overlay analysis in a GIS environment against the fishing ground information derived from passive georeferencing of the fish landing datasets. The resultant attributes were grouped and summarized based on the grid ID and the species caught. This information was used to map the species wise and total catch obtained from the area denoted by each grid.

Results and discussion

The marine fisheries of India, like other tropical fisheries, are highly complex, multi-species, and multi-gear in nature. The sector is broadly classified into three sub-sectors mechanized, motorized, and non-motorized each contributing significantly to the total marine fish production. Along the southwest coast of India, fishing activities are supported by a diverse fleet comprising approximately 8,438 mechanized, 20,689 motorized, and 6,423 non-motorized fishing crafts. These vessels operate from around 290 landing centres, which include both major fishing harbours and minor landing sites distributed along the coastline (CMFRI–FSI–DoF, 2020). Mechanized crafts, which include trawlers, gillnetters, purse seiners, and longliners, operate in offshore and deep-sea waters, undertaking multi-day fishing trips targeting a wide variety of pelagic and demersal resources. Motorized crafts, are primarily engaged in single-day fishing operations within nearshore areas using gillnets, hooks and lines, or ring seines and contribute substantially to the coastal pelagic fishery. Non-motorized crafts, including traditional wooden canoes and catamarans, represent the artisanal sector and are restricted to very nearshore waters. Across these sectors, fishers deploy a wide array of fishing gears — including trawls, gillnets, lines, and seines, along with several regional and seasonal variants — within India's Exclusive Economic Zone (EEZ). Recently, there has been an increase in operational flexibility, with fishers often using multiple gear types (e.g., trawl, gillnet, and line) during a single fishing voyage, depending on resource availability and target species.

Tunas have been exploited along the Indian coast, with neritic tunas forming the primary component of the tuna fishery until recent years. The fishery traditionally relied on coastal-based fleets of varying specifications, employing diverse craft–gear combinations. With the growing demand in international markets and the development of infrastructure for handling, processing, and export, oceanic tunas became an important component of India's marine fishery sector. Tuna fisheries in India thus evolved from a traditional, coastal, artisanal activity into a commercially significant fishery with both domestic and export orientation.

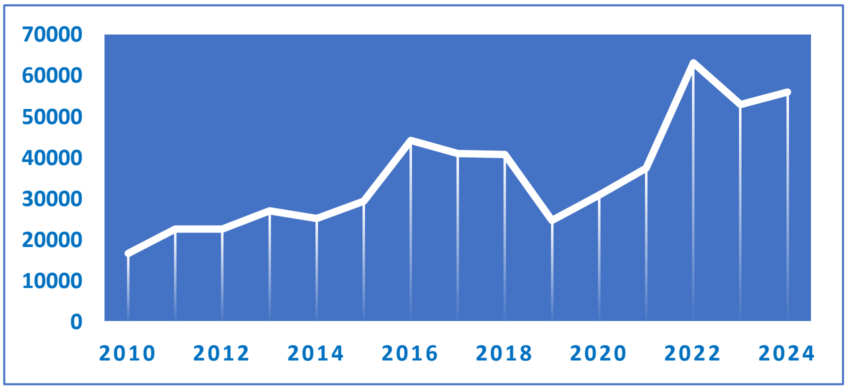

Fig.4 Estimated landings of Tuna resources along the southwest

Tuna fishery over the years has undergone several changes like modernisation of fishing practices along with diversification, intensification and extension of fishing to new grounds. The estimated average annual landings of tunas during the 2010-24 period along southwest coast was 35705 t (Fig.4).

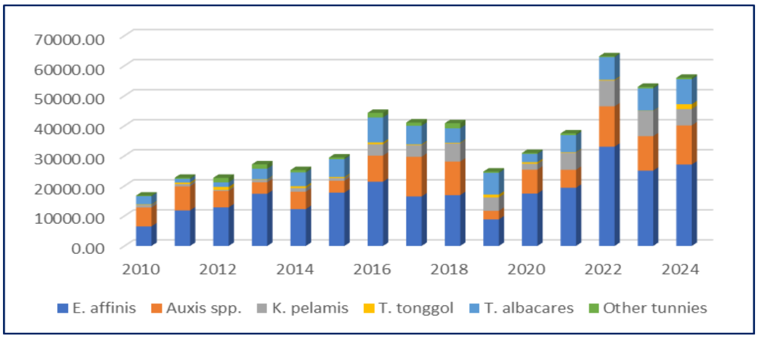

Fig.5 Species-wise distribution and landings of tuna resources

Tuna fishery is supported by nine species, five coastal & neritic species and four oceanic species (Abdussamad *et al*., 2021, Azeez *et al*, 2024). The coastal tunas dominating the landings were *Euthynnus afinis, Auxis thazard* and *Auxis rochei* while oceanic species included *Thunnus tonggol, T. albacares and Katsuwonus pelamis* (Fig.5).

During 2024, the marine fish harvest from this region was estimated at 1.41 million tonnes, of which tuna resources accounted for nearly 5%. Coastal tunas dominated the catch by representing 72% of the total tuna landings and were represented mainly by *Euthynnus*

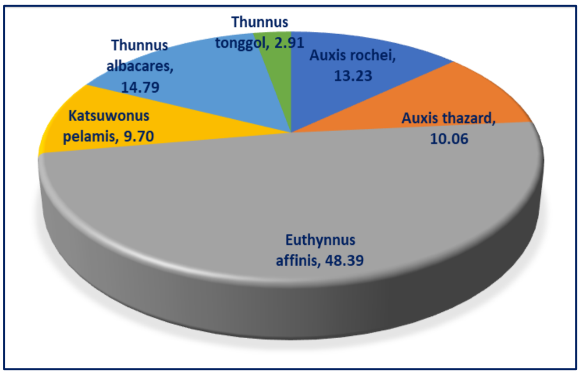

Fig.6 Proportional contribution of tuna species to total landings

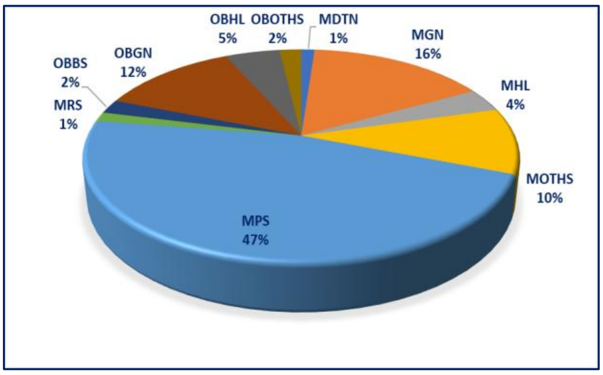

Fig.7 Contribution of different gears to tuna landings

affinis (48.4%), *Auxis thazard* (10.1%) and *Auxis rochei* (13.2%). Oceanic tunas in the landing were dominated by yellowfin tuna, 14.79%, followed by skipjack tuna, *Katsuwonus pelamis* (9.7%), along with nominal quantity of *Thunnus tonggol* (Fig.6). Major gears employed for the harvest of these resources were mechanized purseseines, gillnets and hooks & lines and combined gear operations of trawl and hook & lines (Fig.7).

Seasonal shifts in catch composition were observed, with distinct differences in the spatial distribution of tuna species throughout the year. Coastal tuna species such as *Euthynnus affinis* and *Auxis thazard* exhibited higher catch rates during the post-monsoon months (October–December), coinciding with periods of increased productivity in nearshore waters. During these months, the fishing effort was concentrated closer to shore, particularly off the coasts of Kerala and Karnataka.

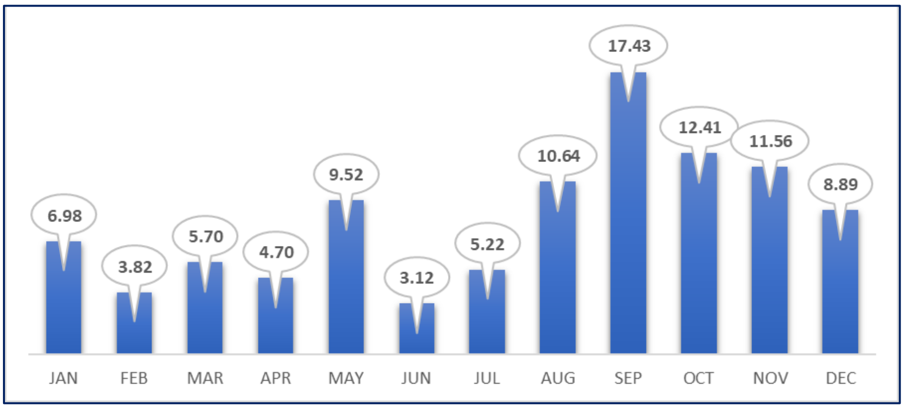

Fig.8 Monthly trends in tuna resources

The distribution of coastal tunas closely aligned with environmental factors such as upwelling intensity, sea surface temperature, and prey availability, which likely influenced their abundance and distribution. Oceanic species were caught more frequently during the pre-monsoon and monsoon periods (April–September), likely due to changes in environmental conditions and prey distribution in deeper waters. The most productive month was found to be September contributing nearly 17.4 % of the landings in South West region followed by October (12.4%) and November (11.6%) (Fig.8).

Spatial distribution of tuna resources

Information was collected from sampled fishing boats through direct field observations and structured interviews with fishers. Data recorded included fishing effort, gear type, duration of operation, distance and bearing from the shore, depth of fishing, and species composition. The Haversine formula was then applied to these parameters, using the known geographic coordinates of the respective landing centres as the starting point for each fishing trip. In total, 2,794 field observations were carried out, covering 3,356 fishing crafts. This enabled the geo-referencing of individual fishing trips and provided an estimated spatial location of the fishing grounds for each sampled vessel. The spatial distribution of tuna landings was analyzed using the geo-referenced information of fishing crafts operating from two major tuna landing centres—Cochin and Neendakara—along the southwest coast of India. Cochin Fisheries Harbour in Kochi, Kerala, situated along the Arabian Sea coast, is one of the major fishing harbours on the southwest coast of India. Similarly, Neendakara Fisheries Harbour provides critical infrastructure for mechanized and motorized fishing fleets operating in the region. Together, these two harbours accounted for nearly 27% of the total tuna landings in the region, with *Euthynnus affinis, Thunnus albacares* and *Katsuwonus pelamis* contributing the maximum share. Maps generated from this analysis revealed distinct spatial patterns in tuna landings.

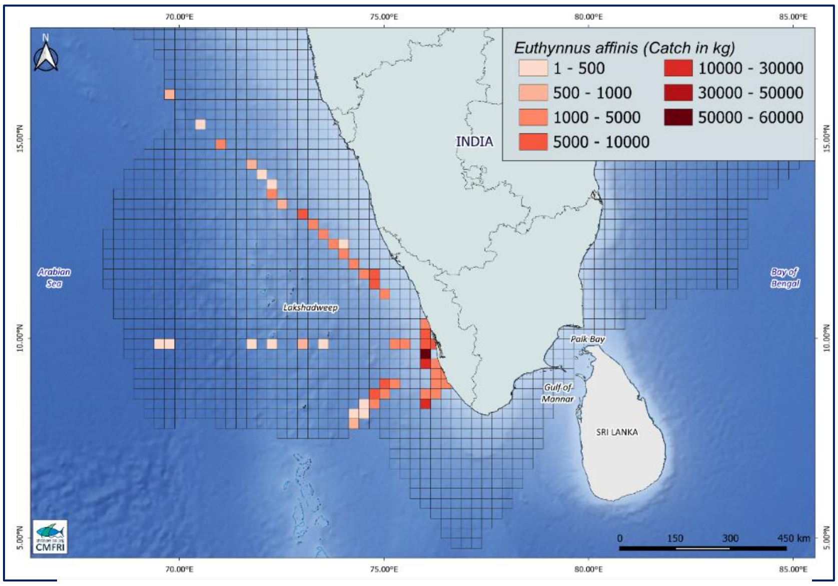

Fig.9 Spatial distribution of *Euthynnus affinis*

Coastal tuna species *Euthynnus affinis,* were predominantly exploited within 20–60 km from the shoreline, with the highest fishing activity observed off the Kerala and Karnataka coasts (Fig.9). This species made up 24% of the total tuna landings from Cochin and Neendakara. The highest catch intensity is observed in the grid cells shaded in the darkest red, where recorded catches exceed 30,000–60,000 kg. This area aligns with the highly productive upwelling zones formed during the southwest monsoon, which enhance primary and secondary productivity and, in turn, attract pelagic predators such as *E.*

affinis. Moderate catch zones, extend westward approximately 100–200 km from the coastline, indicating active fishing grounds across both coastal and near-oceanic waters.

The remaining 72% of landings were contributed by the oceanic species *Thunnus albacares* and *Katsuwonus pelamis* which were predominantly captured beyond 100 km offshore by mechanized longliners and other deep-sea vessels (Fig.10).

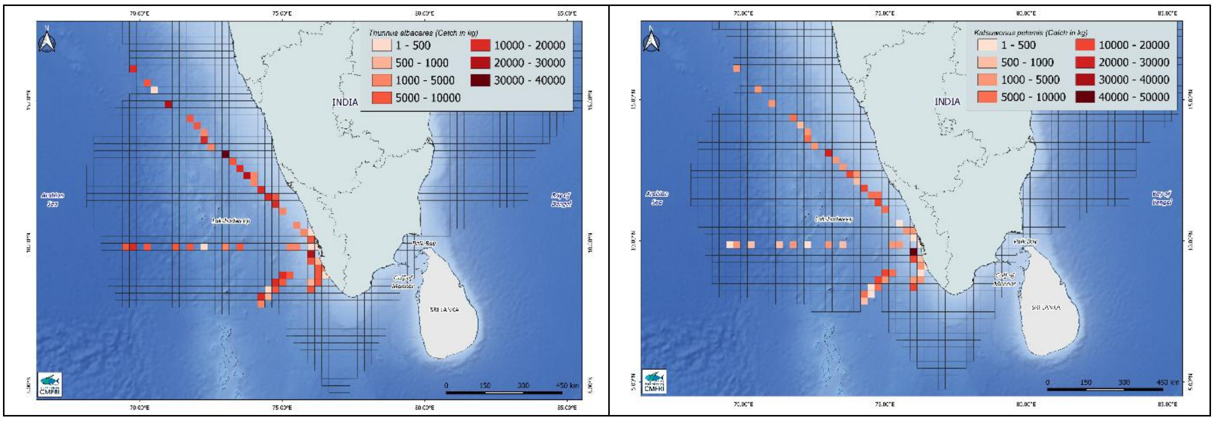

Fig.10 Spatial distribution of *Thunnus albacares* and *Katsuwonus pelamis*

The highest catch intensities, are observed in the offshore grids indicating that these regions form the principal fishing grounds for yellowfin tuna. The types of fishing fleets operated in the sampled area were gillnets, trawlnets purse seiners and liners. Major share of the catch came from fleets which employ multiple gear types (e.g., trawl, gillnet, and line) during a single voyage. Analysis of spatially explicit landing data reveals distinct geographical preferences for the major commercial tuna species, reflecting species-specific ecological requirements. The distribution of each species could be mapped in relation to its seasonal occurrence and abundance. In conventional landing-based fishery assessments, the exact fishing grounds from which the species were caught often remained unknown. However, the present study has enabled the identification of these locations, providing information on the spatio-temporal distribution of most of the tuna species landed in Cochin and Needakara fishing harbours along the southwest coast.

Conclusions

The geo-referencing of fishing trips enabled the mapping of tuna landings to their probable fishing grounds, offering valuable spatial insights into fishing effort and resource distribution. Tuna display strong spatial variability influenced by oceanographic features like upwelling zones, thermal fronts, and convergence areas where prey is abundant. Spatial mapping tools, allow managers to visualize and quantify these patterns, leading to data-driven decision-making. These findings enhance the understanding of species-specific fishing patterns, habitat preferences, and seasonal dynamics, contributing significantly to the development of spatially explicit and sustainable fisheries management strategies for the region.

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