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Harnessing GIS to map trawl fishing grounds and reduce carbon footprint along India's west coast

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Abstract

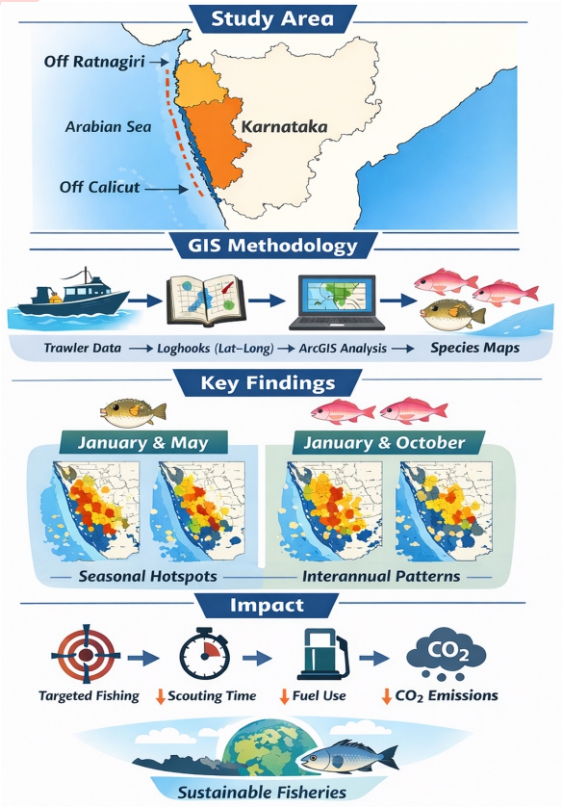
Aim: This study examines the spatial and temporal dynamics of key commercial fish species along the west coast of India through GIS-based mapping, aiming to reduce the environmental footprint of trawl fisheries by optimizing fishing effort, minimizing scouting time, and lowering carbon emissions.

Methodology: Data from customised logbooks for each fishing operation were geo-referenced using recorded latitude–longitude coordinates to delineate the spatial extent of fishing grounds. Spatial analysis and map generation were conducted using ArcGIS, while Visual Basic 6 was used for database management and query execution. The datasets were used to generate thematic layers, shapefiles, and feature classes for spatio-temporal analysis of fishing activities and species distribution.

Results: Three commercially important species/groups—*Trichiurus lepturus, Nemipterus* spp. (*N. japonicus* and *N. randalli*), and *Lagocephalus inermis*—showed consistent occurrence within trawling grounds, with clear seasonal fluctuations in abundance. Peak abundances of *Nemipterus* spp. in January and October and *Lagocephalus inermis* in January and May, indicating persistent species–habitat associations across seasons.

Interpretation: The findings of this study highlight the utility of participatory GIS-based mapping in identifying productive fishing grounds and supporting adaptive, season-specific fisheries management, and conservation planning. Practically, the spatial information generated can help fishers reduce scouting time, fuel consumption, and operational costs by targeting areas of consistent abundance, thereby also contributing to lower greenhouse gas emissions from trawling operations.

Key words: Climate change, CO_2 emission, Fisheries, Fishing grounds, Mitigation, Trawl



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Introduction

Carbon emissions are a primary driver of climate change, largely originating from the combustion of fossil fuels such as coal, oil, and natural gas for energy and transportation. Carbon sequestration could be an effective way to reduce atmospheric carbon dioxide which is the most important greenhouse gas (Beer *et al.,* 2024). The fisheries sector, like many other industries, contributes to carbon emissions mainly through fuel consumption by fishing vessels, transportation of fish from fishing grounds to processing and market centres, and energy-intensive refrigeration and storage processes (Jennings and Wilson, 2009). In response, several sectors have initiated efforts to reduce environmental impacts and greenhouse gas emissions. Accordingly, fisheries management has evolved to incorporate environmental conservation and emission reduction as a third critical dimension, alongside quality and cost considerations (Watanabe and Tahara, 2016). In India, nearly 80% of marine fish production originates from the mechanized sector, with multiday trawlers contributing the largest share of the catch. In Karnataka, trawlers account for approximately 70% of total marine landings (CMFRI, 2022), highlighting their significant role in both fisheries production and associated carbon emissions.

The application of Geographic Information Systems (GIS) in marine and coastal resource management has expanded considerably in recent years. The strength of GIS lies in its capacity to address spatially explicit problems and to generate map-based representations of complex ecosystem interactions and processes, enabling resource managers to better comprehend these dynamics and apply them effectively in decision-making (Rahel, 2004). In fisheries resource management, GIS serves as a powerful analytical tool by integrating spatial and non-spatial data to map the distribution of fish stocks, fishing effort, and associated environmental variables. Such spatial insights facilitate the identification of overfished areas, optimization of fishing grounds, and assessment of stock health. Furthermore, GIS enables the analysis of vessel-based data to track fishing activities and infer fish movement patterns, while also evaluating the influence of environmental drivers on fish distribution and abundance. Overall, GIS provides critical, data-driven insights that support informed management decisions and promote sustainable fisheries.

The application of Geographic Information Systems (GIS) in fisheries expanded significantly during the 1990s, with primary emphasis on the assessment of fish habitats, resources, ecosystems, and broader marine environment (Meaden, 2001). In recent years, trawlers have increasingly been equipped with GIS-based technologies to optimize fishing operations. These tools enable the identification of productive fishing grounds, tracking of fish schools, and enhancement of fishing accuracy and operational efficiency. GIS also provides critical information on the spatial distribution of marine resources, species composition, and prevailing environmental conditions within fishing areas. The adoption of GIS technologies contributes to reduced fuel consumption, minimized fishing waste, and lower ecological impacts of trawling activities. Multiday trawlers operating in Indian waters now employ advanced, state-of-the-art technologies, including deep-water fishing capabilities, sophisticated fish-finding instruments, and GPS-based navigation systems. Catch data generated from these trawlers effectively reflect the spatial distribution of fishery resources across commercial fishing grounds. Earlier studies in India pioneered the use of Participatory GIS (PGIS) for marine resource mapping, marking a first-of-its-kind initiative in Indian marine fisheries (Dineshbabu *et al.,* 2012). The development of a spatial database through active participation of fishermen offers valuable inputs for fisheries management and policy formulation. The present study analyzes fishery resource mapping along the west coast of India, conducted in collaboration with progressive fishermen, and demonstrates how GIS-based insights can aid in identifying strategies to reduce carbon emissions from the fishing sector.

Materials and Methods

Study area: The study area (Fig. 1) is located in the South-eastern Arabian Sea, off the coast of Karnataka, Goa and part of Kerala and Maharashtra extending between 11.969° N, 71.794° E and 18.821° N, 74.932° E. The region encompasses major trawling grounds along the west coast and extends latitudinally to depths of up to 200 m. Fishing activities in this area are primarily conducted at depths ranging from 20 to 200 m, representing the principal commercial fishing zone for a wide variety of exploited marine species in the region.

Data collection

Fishery data collection: Fishery data were collected using a stratified, multi-stage random sampling design to estimate trawl landings, incorporating both spatial and temporal stratification. Sampling strata were based on fishing zones, seasonal fishing periods, and landing centres. Representative multiday trawlers operating from Mangalore fishing harbour were selected randomly within each stratum for onboard data collection. The South-eastern Arabian Sea was divided into non-overlapping zones based on fishing intensity and geographical characteristics (Srinath *et al.,* 2005). Weekly catch data (kg) were obtained from pre-identified commercial trawlers based at Mangalore and operated along Karnataka, Goa, and part of Kerala and Maharashtra over the period between 2008 and 2016. The sampled vessels had an average overall length (OAL) of 15.85 ± 1.2 m and engine power of approximately powered by 160 ± 20 HP, conducting multi-day trawling operations of 8–13 days at depths ranging from 20 to 200 m.A total of 2,562 trawling days were analysed, covering an average fishing area of 35,634 km². Catch data from 2008 to 2016 were examined for consistency using secondary datasets from the National Marine Fisheries Data Centre (NMFDC) and the Central Marine Fisheries Research Institute (CMFRI, 2022).

Onboard data collection: Onboard data were recorded using customized log sheets, with crew members of the sampled

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vessels trained for systematic data entry. The database included information on vessel speed, fishing days and dates, fishing locations, depths, shooting and hauling times, number of hauls, net types, mesh sizes, total hauls, catch quantity, discards, and species composition (Dineshbabu *et al.,* 2016). Data on major commercial species were extracted exclusively from fishermen-maintained logbooks, which documented all species encountered during fishing operations. Catch per Hour (CPH) was calculated using quality-checked data on estimated catch and total fishing hours after excluding incomplete or inconsistent logbook entries. Species were classified following Fischer and Bianchi (1984).

Spatial Data and GIS Analysis: Spatial data were acquired for GIS-based analysis using ArcGIS and Visual Basic 6 for efficient data management and spatio-temporal mapping. The Visual Basic 6 platform was originally developed in 2008 as a customized fisheries GIS application has since been continuously maintained to ensure compatibility with long-term legacy datasets and standardized workflows.

Results and Discussion

The present study employed GIS-based mapping to comprehensively analyse the spatial and temporal characteristics of trawling grounds within the multi-day fishing area along the west coast of India. Through systematic resource mapping, the abundance of approximately 269 marine species was quantified using catch per hour (CPH), providing a detailed understanding of species distribution and relative abundance across the trawling grounds. Although the analysis encompassed all recorded species, three commercially dominant and consistently distributed species/groups were selected to demonstrate the applicability of GIS-based approaches and spatial repeatability analysis in this study. Fishery-dependent data collected through trawler logbooks enabled delineation of trawling grounds off the Karnataka coast.

The trawlers originating from Karnataka extended their fishing operations from off Calicut in Kerala to off Ratnagiri in Maharashtra, covering extensive fishing grounds across neighbouring states along the west coast of India (Fig. 1). This spatial coverage highlights the scale and operational range of multi-day trawling activities in the region. Although the data used in this study were collected during 2008–2016, the objective was to develop and demonstrate a Geographic Information System (GIS)-based framework for mapping trawl fishing grounds rather than to describe the current status of fishery. The spatial patterns identified are primarily influenced by relatively stable environmental features such as bathymetry and seabed characteristics, making the GIS framework relevant beyond the study period. The findings provide a valuable baseline for understanding fishing ground utilization and demonstrate how spatial mapping can improve fishing efficiency by reducing scouting time, fuel consumption, and associated carbon emissions. The methodology is readily applicable to contemporary fisheries data and can be integrated with vessel tracking systems, electronic logbooks, and recent fisheries datasets to support sustainable fisheries management and ongoing decarbonization efforts.

The participatory GIS (PGIS) approach adopted in this study proved effective in identifying areas of species abundance along the west coast of India. Participatory mapping has been widely used worldwide to generate spatially explicit information by engaging stakeholders and local communities, thereby enhancing the quality and relevance of data for fisheries management and decision-making (Dalton, 2006; Klain and Chan, 2012; Dineshbabu *et al.,* 2012; Burdon *et al.,* 2019; Scully-Engelmeyer *et al.,* 2021). The involvement of fishermen ensured reliable spatial representation of fishing grounds and resource distribution patterns. Previous studies along the Karnataka coast primarily focused on participatory approaches and GIS-based mapping of fishery resources at a regional scale (Kumar *et al.,* 2019; Purbali *et al.,* 2019). In contrast, the present study expands the scope to the entire west coast of India, providing a broader and more comprehensive spatial assessment of fishery resource distribution and seasonal fishing grounds. Unlike previous studies that mainly emphasized on resource mapping, the present investigation specifically highlights the practical application of participatory GIS (PGIS) for reducing scouting time and improving fishing efficiency through the identification of consistent resource-abundant areas. By enabling fishers to directly access spatial information on resource availability, the study demonstrates how targeted fishing operations can reduce unnecessary searching, fuel consumption, operational costs, and associated carbon emissions. GIS-based mapping revealed pronounced spatial and temporal variability in the distribution of marine fauna. Seasonal trawling grounds were clearly delineated for the pre-monsoon (February–May), monsoon (June– September), and post-monsoon (October–January) periods (Fig. 2). The mapping of seasonal fishing grounds provided critical insights into temporal shifts in fishing effort and resource availability, which are essential for designing adaptive and season-specific fisheries management strategies (Vivekanandan *et al.,* 2005).

Significant seasonal variations were observed in the abundance of *Trichiurus lepturus, Nemipterus* spp. (*Nemipterus japonicus* and *Nemipterus randalli*), and *Lagocephalus inermis* (Fig. 3). These three species consistently occurred within the trawling grounds, exhibiting distinct seasonal fluctuations in abundance. Identification of such persistent species and their seasonal abundance patterns is crucial for effective fisheries management, stock assessment and conservation planning (Hoeinghaus *et al.,* 2003; Cope and Haltuch, 2012; Purbali *et al.,* 2019). Overlay analysis of abundance maps across seasons and years revealed a high degree of repeatability in species distribution. This consistency indicates the persistence of favourable habitats and stable resource-use patterns over time. For example, *Nemipterus* spp. (*N. japonicus* and *N. randalli*), showed recurring abundance in January and October (Figs. 4, 5), while *Lagocephalus inermis* demonstrated consistent abundance during January and May (Figs. 6, 7). Such repeatability underscores

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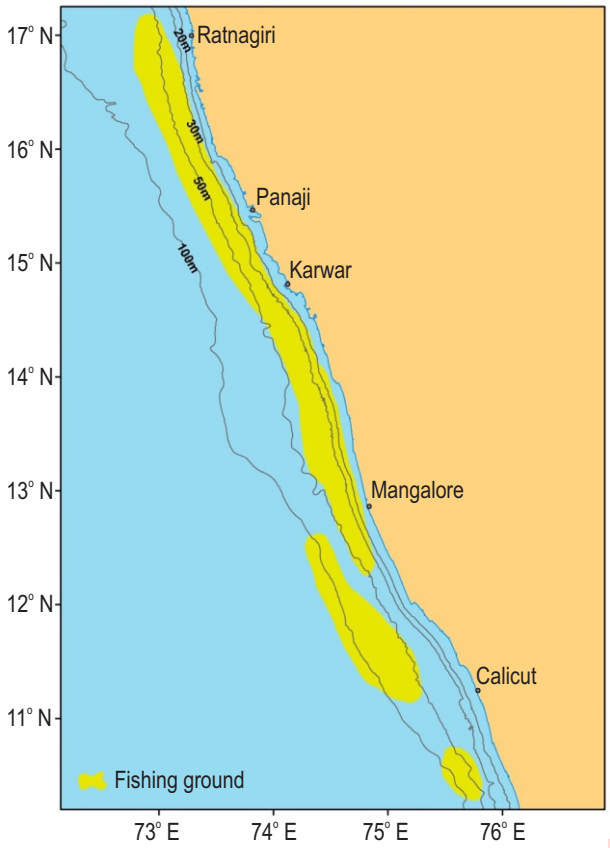


Fig. 1: Trawling grounds off Karnataka, West coast of India.

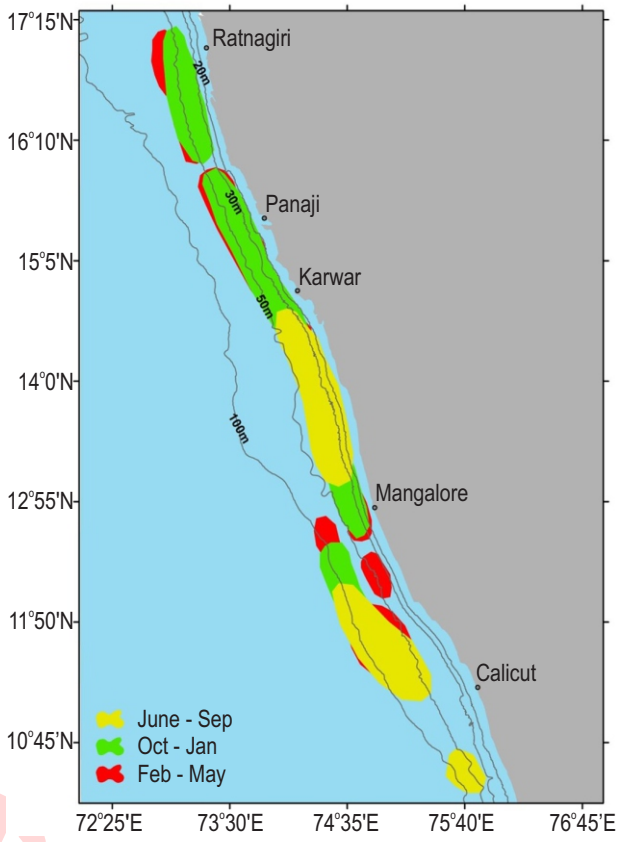


Fig. 2: Seasonal grounds of trawl operation off Karnataka coast.

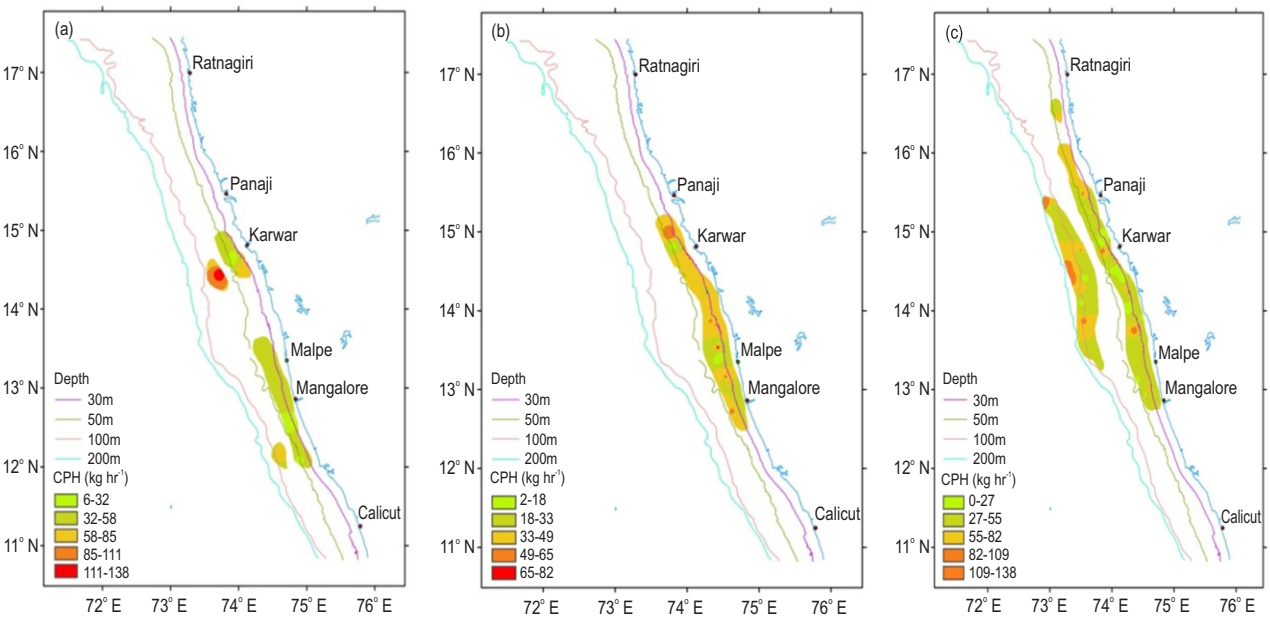


Fig. 3: Seasonal abundance of (a) *Trichiurus lepturus*, (b) *Nemipterus* spp. (*Nemipterus japonicus* and *Nemipterus randalli*) and (c) *Lagocephalus inermis* in trawling grounds off Karnataka west coast of India.

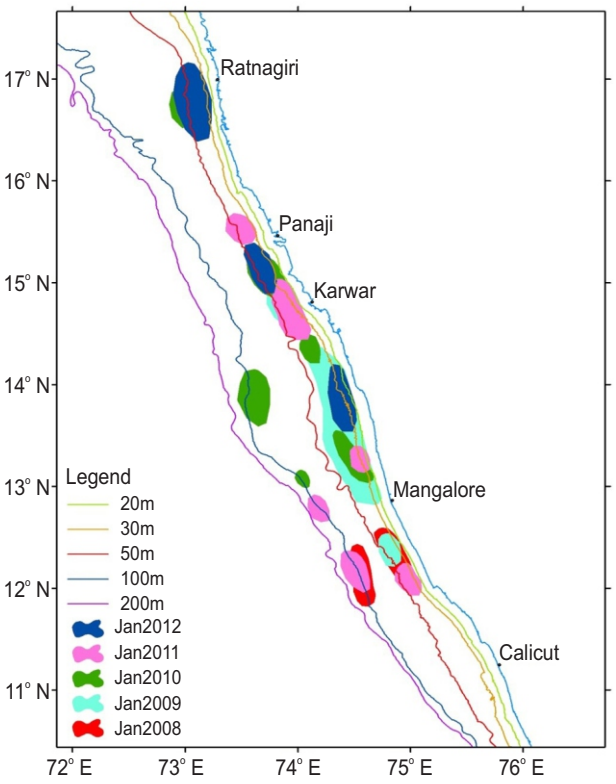


Fig. 4: Repeatability in abundance of *Nemipterus* spp. (*N. japonicus* and *N. randalli*) ground over the years (Jan).

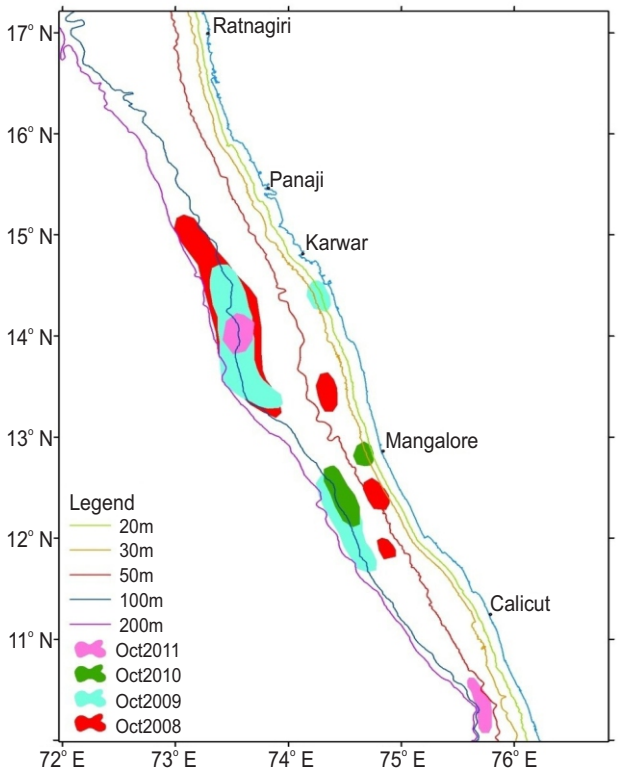


Fig. 5: Repeatability in abundance of *Nemipterus* spp. *Nemipterus* spp. (*N. japonicus* and *N. randalli*) ground over the years (Oct).

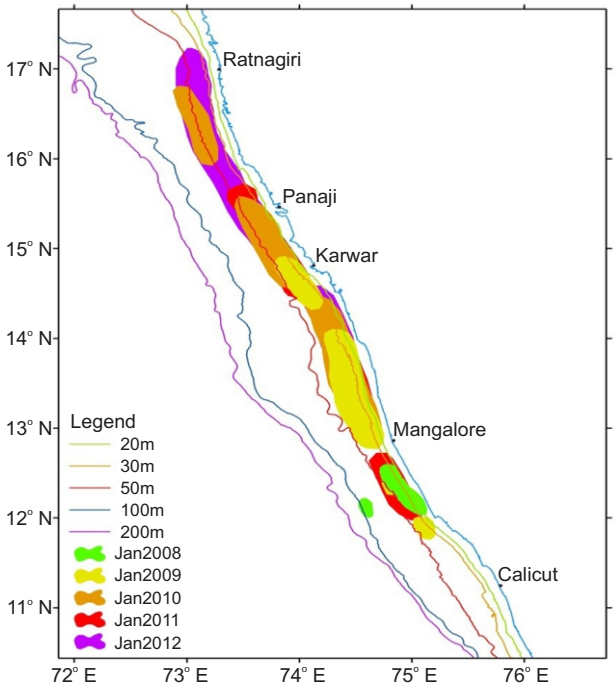


Fig. 6: Repeatability in abundance of *Lagocephalus inermis* ground over the years (Jan).

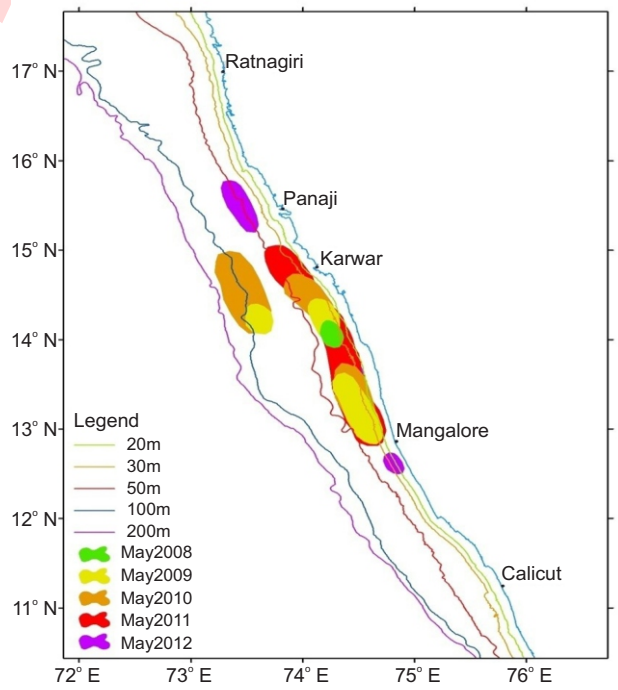


Fig. 7: Repeatability in abundance of *Lagocephalus inermis* ground over the years (May).

the importance of long-term spatial datasets for understanding habitat stability and guiding sustainable fisheries management (Jason, 2010; Piazzi *et al.,* 2012).

In addition to abundance, comprehensive onboard data collection provided information on size structure and maturity stages of major resources. This enabled clear identification of spawning and juvenile grounds within the trawling areas, offering valuable insights into species' reproductive dynamics and life-history patterns (Lahellec *et al.,* 2025). The spatial delineation of spawning and nursery grounds is particularly important for implementing spatial and seasonal fishing regulations aimed at protecting vulnerable life stages. GIS-based resource mapping, thus, serves as a powerful decision-support tool for policy makers in formulating effective management measures, including fishing closures, effort regulation, and the establishment of marine protected areas. By targeting areas of consistent abundance identified through GIS mapping, fishers can minimize unnecessary searching, thereby reducing travel time, fuel consumption and operational costs. Given the fuel-intensive nature of trawling, even modest reductions in scouting effort can lead to substantial decrease in fuel use and greenhouse gas emissions (Gulbrandsen, 2012). Such optimization aligns with global efforts to mitigate climate change and promote sustainability within the fishing sector (Sumaila *et al.,* 2011).

The present study primarily demonstrates the spatial applicability of GIS-based resource mapping for optimizing fishing effort. While direct fuel consumption measurements were not carried out, the reduction in scouting effort inferred from recurring fishing grounds indicates substantial potential for improving fuel efficiency and lowering emissions. Although carbon emissions from Indian trawlers are currently estimated to be approximately 17.3% lower than the global average (Dineshbabu *et al.,* 2024), further reductions are achievable through optimized fishing routes and informed spatial planning. Integration of GIS-derived resource maps into fishing strategies can, therefore, enhance both environmental performance and economic efficiency. Reduced scouting time also offers broader ecological and socio-economic benefits. Limiting vessel movement across sensitive habitats such as coral reefs and seagrass beds can help minimize habitat disturbance and biodiversity loss (Worm *et al.,* 2006; Worm *et al.,* 2009). Simultaneously, improved fuel efficiency lowers operational costs, strengthening the economic resilience of fishers and supporting long-term sustainability of coastal livelihoods (Costello *et al.,* 2016). Overall, the integration of GIS-based mapping with participatory data collection provides a robust framework for understanding resource distribution, optimizing fishing effort, reducing carbon emissions, and supporting sustainable fisheries management. By leveraging spatially explicit information on species abundance and habitat use, this approach contributes not only to improved fisheries governance, but also to broader climate change mitigation and marine conservation goals.

The participatory GIS approach adopted in this study effectively generated spatially explicit information on the seasonal abundance and distribution of key trawl resources along the west coast of India. Three commercially important species/groups—*Trichiurus lepturus, Nemipterus* spp. (*N. japonicus* and *N. randalli*), and *Lagocephalus inermis*—showed consistent occurrence within trawling grounds, with clear seasonal fluctuations in abundance. Overlay analysis of abundance maps across seasons and years demonstrated a high degree of repeatability in species distribution, indicating stable habitats and persistent resource-use patterns. These findings highlight the utility of PGIS-based mapping in identifying productive fishing grounds and supporting adaptive, season-specific fisheries management, and conservation planning. Practically, the spatial information generated can help fishers reduce scouting time, fuel consumption, and operational costs by targeting areas of consistent abundance, thereby also contributing to lower greenhouse gas emissions from trawling operations.

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Authors' contribution: S. Thomas: Conceptualization, Data collection, Methodology, Investigation, Data analysis, Writing-original draft; **K.M. Rajesh:** Conceptualization, Methodology, Investigation, Data analysis, Writing – revision and editing; **A.P. Dineshbabu:** Conceptualization, Data collection, Methodology, Investigation, Data analysis, Writing – revision and editing.

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Conflict of interest: The authors have no competing interests to declare that are relevant to the content of this article.

Data availability: All data generated or analyzed during this study are included in this article.

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