Species-specific Fishery Advisory Development for Hilsa, Oil Sardine and Yellowfin Tuna
&
Strategies for PFZ validation

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22 February 2023

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Journey from the traditional fishing knowledge to science based knowledge

Background

- Fishing is one of the oldest activities practiced by the human being and still a huge population depend on fishing worldwide.

- Traditionally, the success of fishing depends on the fishermen's keen sense of site selection, therefore the ‘good catch’ is mostly ascribed to the ‘luck of fishermen’. As a result fishermen often return with ‘low catch’ even after spending many days in the sea.

- It was necessary to come up with scientific investigation to pre-determine the probable fishing locations, so that the fishermen should not return empty handed.

Challenges

- Locating fish shoal is very much challenging as the fishes dwindle and move to any other region.

- Increase in search time for fishes also increases fuel consumption and human effort.

- Reliable and timely forecast of the potential fishing zones (PFZ) of fish aggregation that will reduce the search time and fuel consumption.

Scientific approach for identifying PFZ

- Visual spotting from the aircraft of some of the pelagic fishes like Anchovy, Swordfish, Tuna was successfully demonstrated in the Western countries. However, use of aircraft for locating fish schools on regular basis is not the cost effective and viable option.

- As an alternative, use of satellite remote sensing is the best approach for identifying potential fishing grounds. Though the fish schools can't be directly visible from the satellite altitudes, but indirectly it can help to identify the zones of fish aggregation.

- Sea surface temperature (SST) is considered as one of the import oceanic parameters that can be successfully measured through satellite remote sensing.

- SST is indicator of different oceanic processes like upwelling, fronts etc.

- In addition to SST, Phytoplankton biomass (chlorophyll conc.) is also considered, as it is indicative of the availability of food for fishes.

- Information about the food availability is an important factor that controls the occurrence, abundance and migration of the fishes in the sea.

Remote sensing approach for identifying Potential Fishing Zone (PFZ)

- ❑ Ocean color data directly provide the information about the productive regions where fishes can aggregate for availability of food.

- ❑ SST features also indicate the suitable environment for different fish species aggregation.

- ❑ Combination and matching of both the SST and Chlorophyll features indicate:

    - The regions with enhanced primary production (through Ocean Color data)

    - Whether the nutrient rich water is available at the site of primary production or not (through SST features)

    - Co-incidence of both the SST and Chlorophyll features in a particular region indicates the coupled physical and biogeochemical processes.

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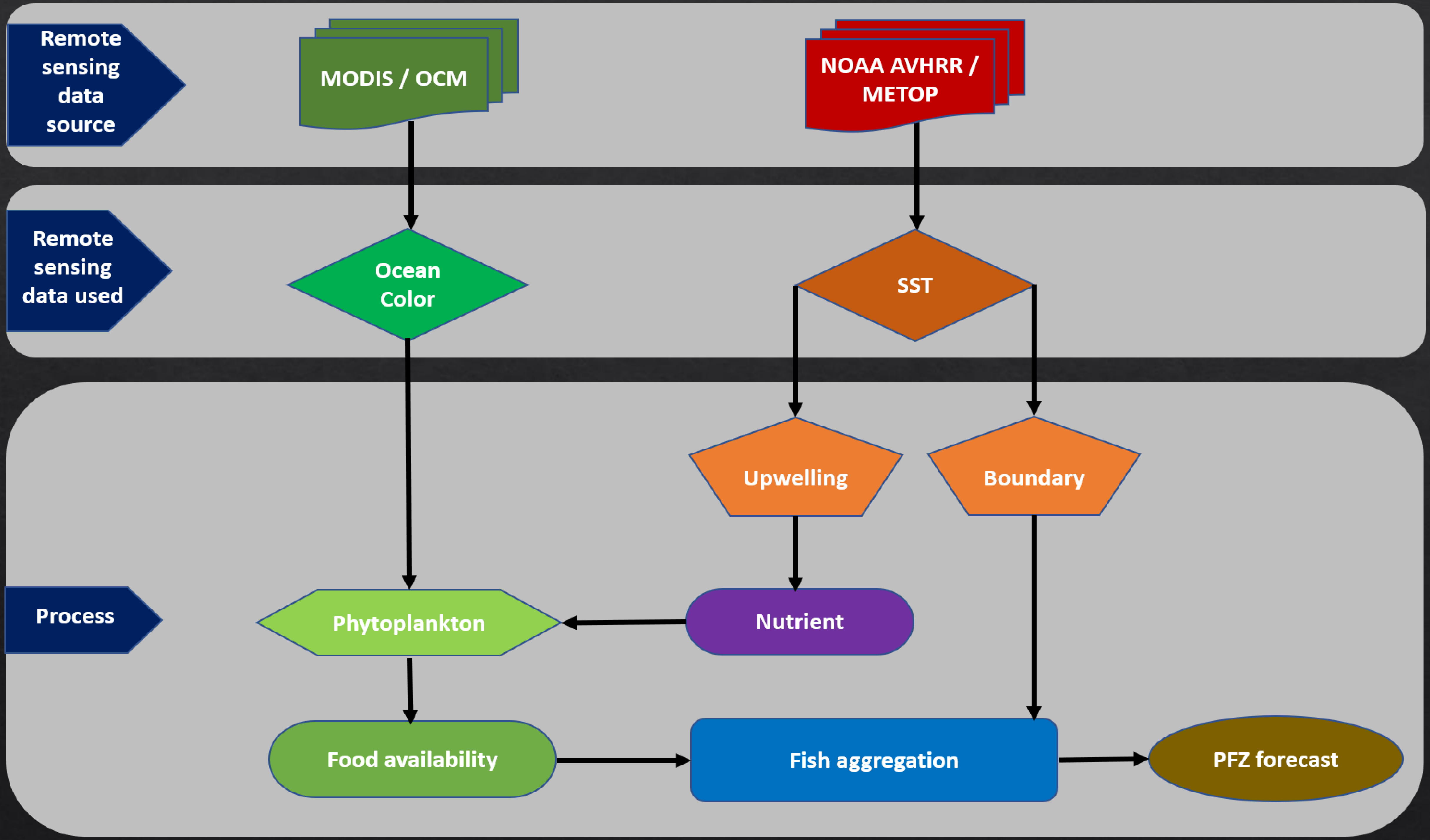

Remote sensing data source
MODIS / OCM
NOAA AVHRR / METOP
Remote sensing data used
Ocean Color
SST
Upwelling
Boundary
Process
Phytoplankton
Nutrient
Food availability
Fish aggregation
PFZ forecast

Other important oceanographic and meteorological parameters having implications for fisheries:

- Salinity
- Turbidity
- Dissolved oxygen
- Mixed layer depth
- Water currents
- Nutrient concentration
- Wind

species-specific fishery advisory

Why species-specific fishery advisory is important?

- Developing species-specific fishery advisory for some fish species is important due to the following reasons:
  - Demand among the consumers
  - Economic importance
  - Population decline
  - Better management and policy making purposes

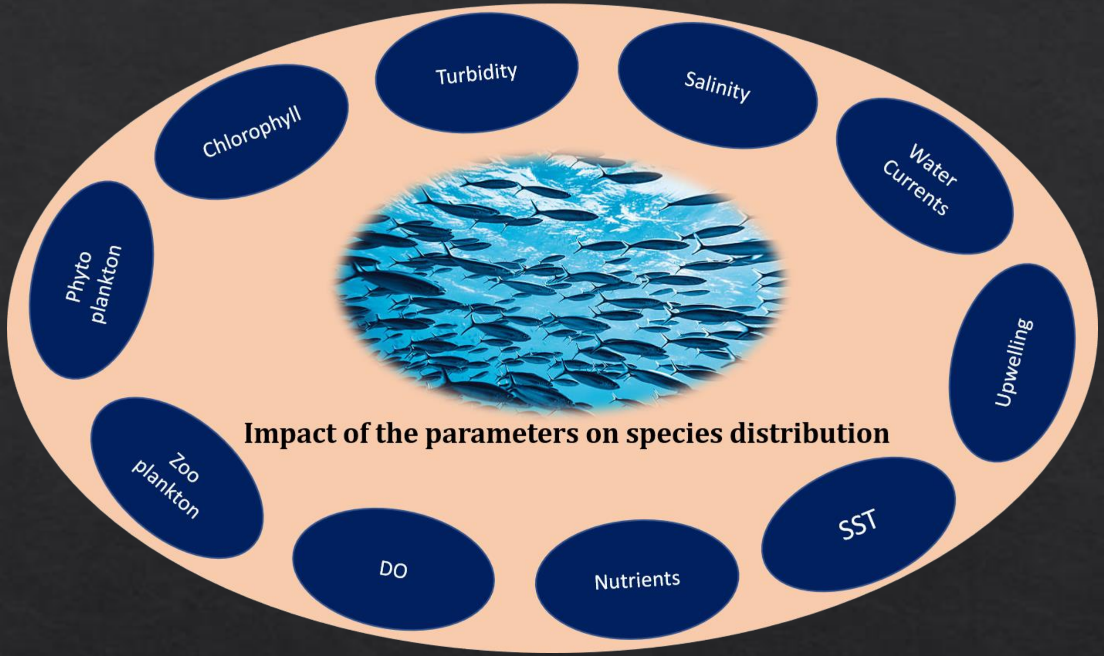
Why developing Hilsa, Oil sardine and Yellowfin Tuna advisory is important

- Hilsa is one of the highest-priced fish species in the Indian sub-continent.
- Around 15-20% of the global Hilsa catch is contributed from India of which the majority of the production (70-80%) comes from the state of West Bengal.
- Livelihood of 0.46 million coastal fisher folk in West Bengal is dependent upon Hilsa fishery.
- Recent exploitation rate of Hilsa (0.81) has exceeded the maximum exploitation rate (0.78).

- Oil sardine constitute the most important single species marine fishery resource in India in terms of landing volume (around 17-20% of the total marine fish landings in India).
- Kerala alone contributes ~45% of the total catch.
- In the recent decade, a declining trend is observed since 2015.

- Tuna is one of the commercially important deep-sea fishery resources in India.
- Source of very high-quality protein. Therefore, huge demand for Yellowfin Tuna among consumers.
- The species is overfished.

How to locate the zones of fish species abundance



- ❑ Good understanding on the fish species biology.

- ❑ Understanding the relationship between different oceanic parameters/processes and spatial distribution of fish species.

- ❑ Use of those understanding in certain models to delineate high abundance zones of the species.

Research towards developing Hilsa fishery advisory for West Bengal

General Characteristics of Hilsa

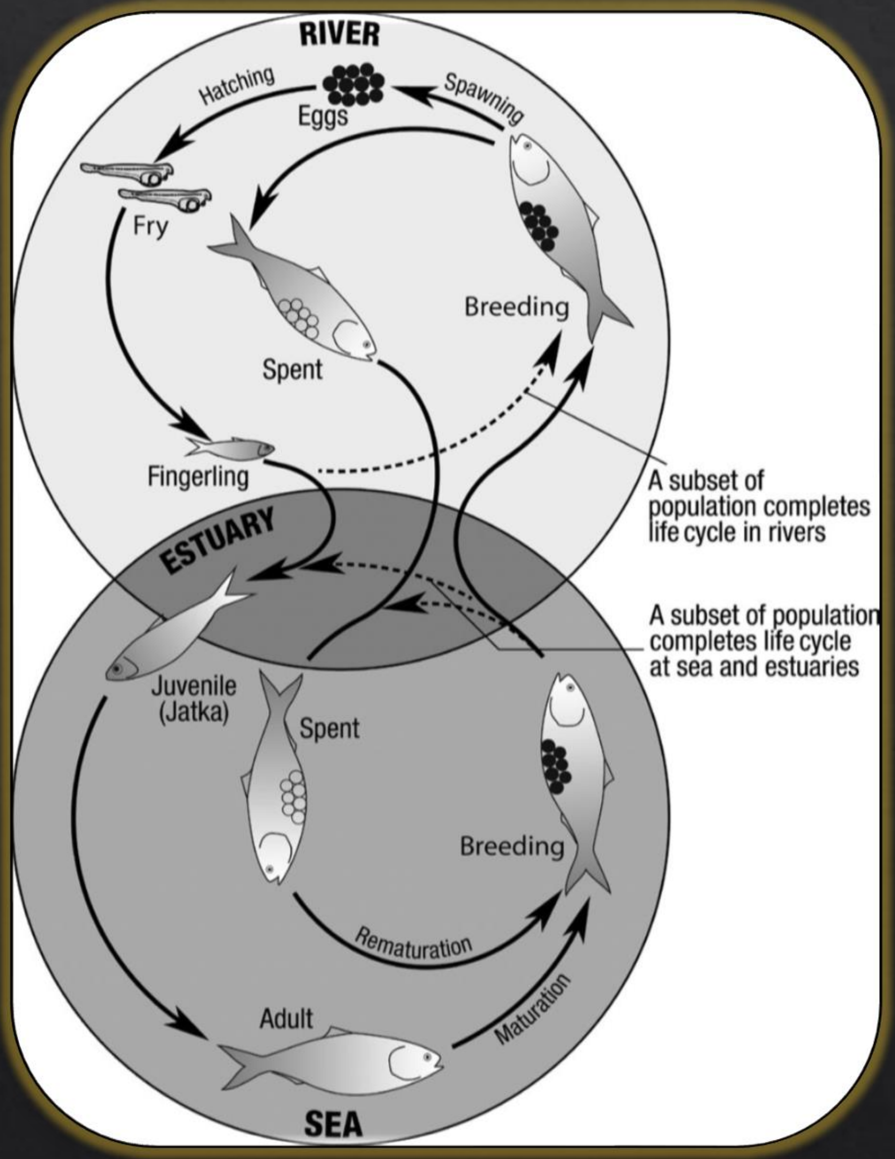
- Hilsa (*Tenualosa ilisha*) is an anadromous fish that spend most of its life span in the ocean, feeds on phytoplankton, and makes the breeding migration towards the river and estuary as the southwest monsoon intensifies.

- The peak breeding period is from June to October.

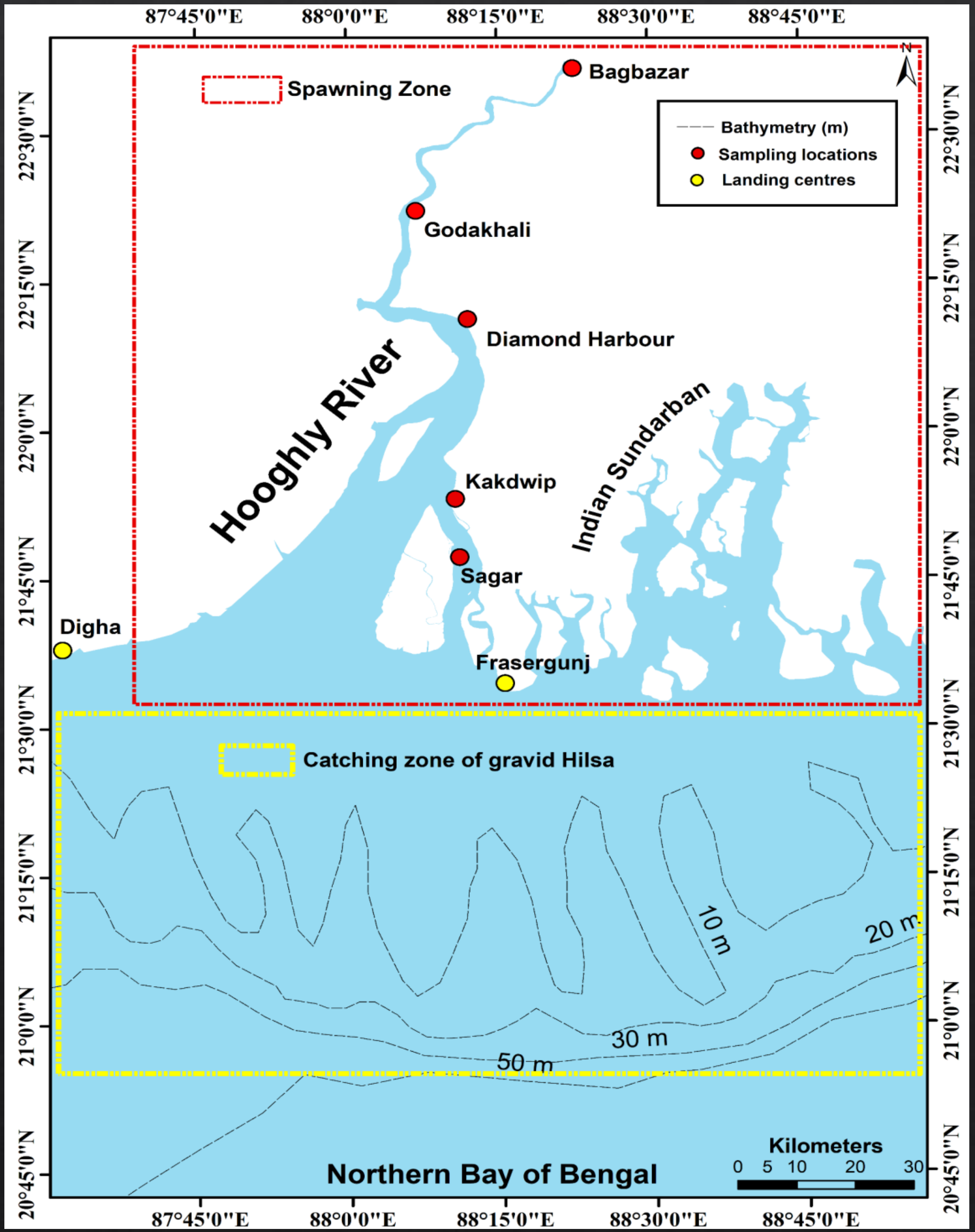
- The decrease in salinity caused by the river discharge and rain over the sea triggers the Hilsa to migrate towards the estuary and river.

- In adults, partial cessation of feeding is observed before feeding.

- The migration and breeding behaviour are regulated by various oceanic and environmental factors.



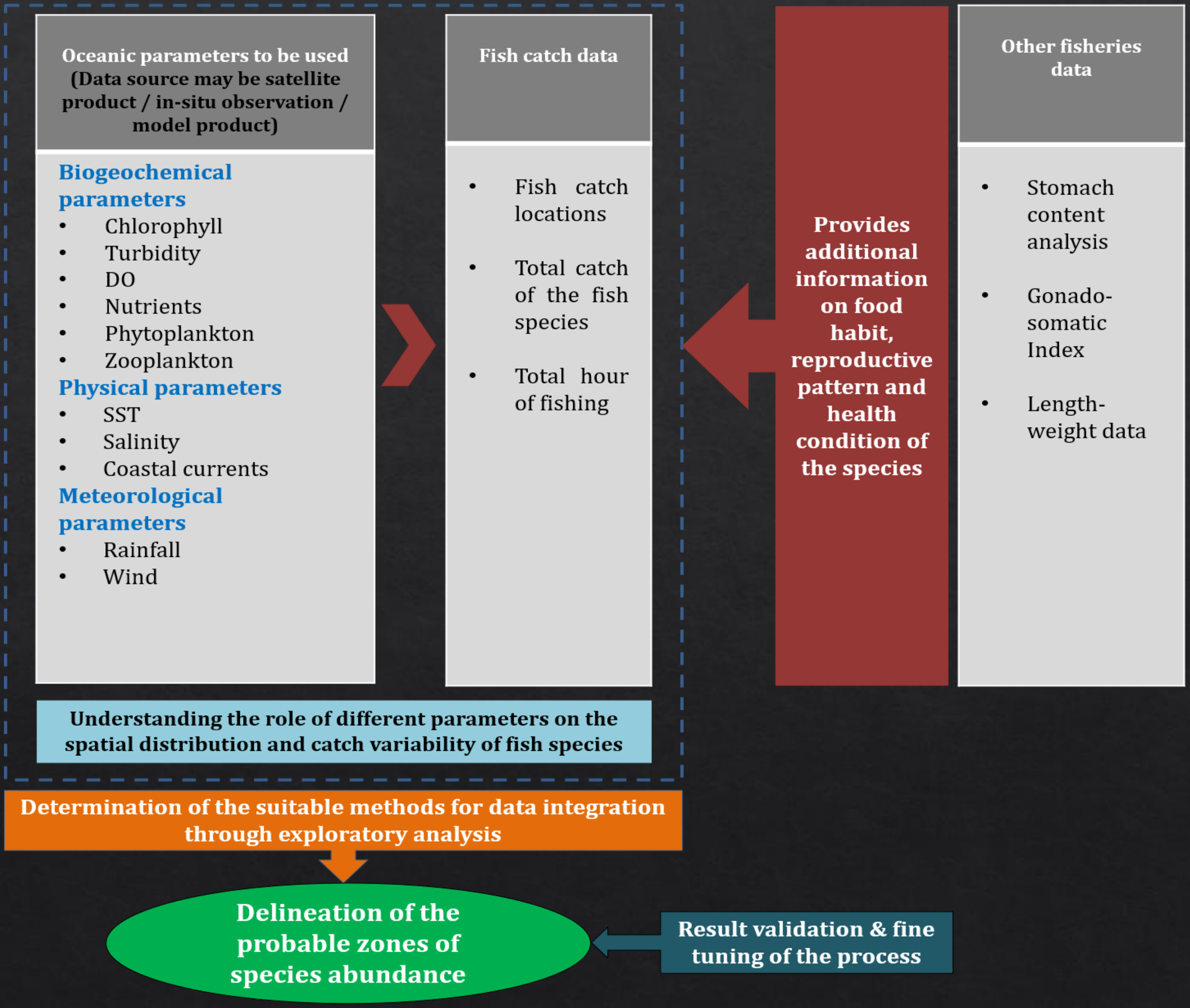
(Source: Hossain et al., 2016)



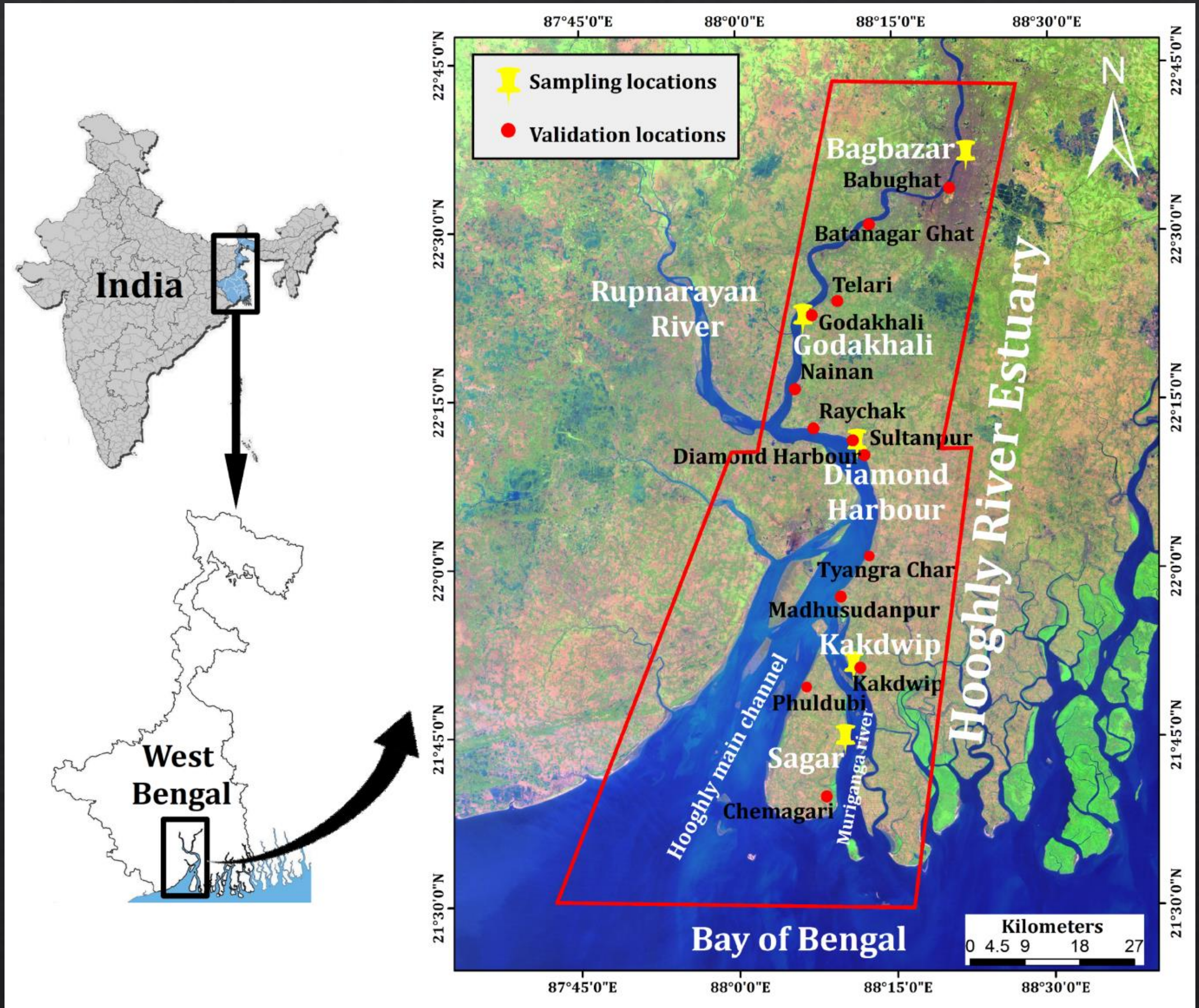
Bottleneck

The preferred spawning area of the fish is river or estuary, but major catch takes place in the coastal water when they are either migrating riverward for spawning or coming back to the coastal water after spawning.

Conceptual framework for Hilsa habitat suitability analysis and development of experimental Hilsa fishery advisory



Case study – 1: Habitat suitability analysis of juvenile Hilsa in the Hugli River Estuary



Source: Giri, S., Chanda, A., Mondal, P. P., Samanta, S., Chakraborty, K., Maity, S., & Hazra, S. (2021). Role of biogeochemical parameters in delineating suitable habitats of juvenile Hilsa (*Tenualosa ilisha*) within an estuary. *Environmental Biology of Fishes*, *104*(9), 1057-1072.

Research Approach

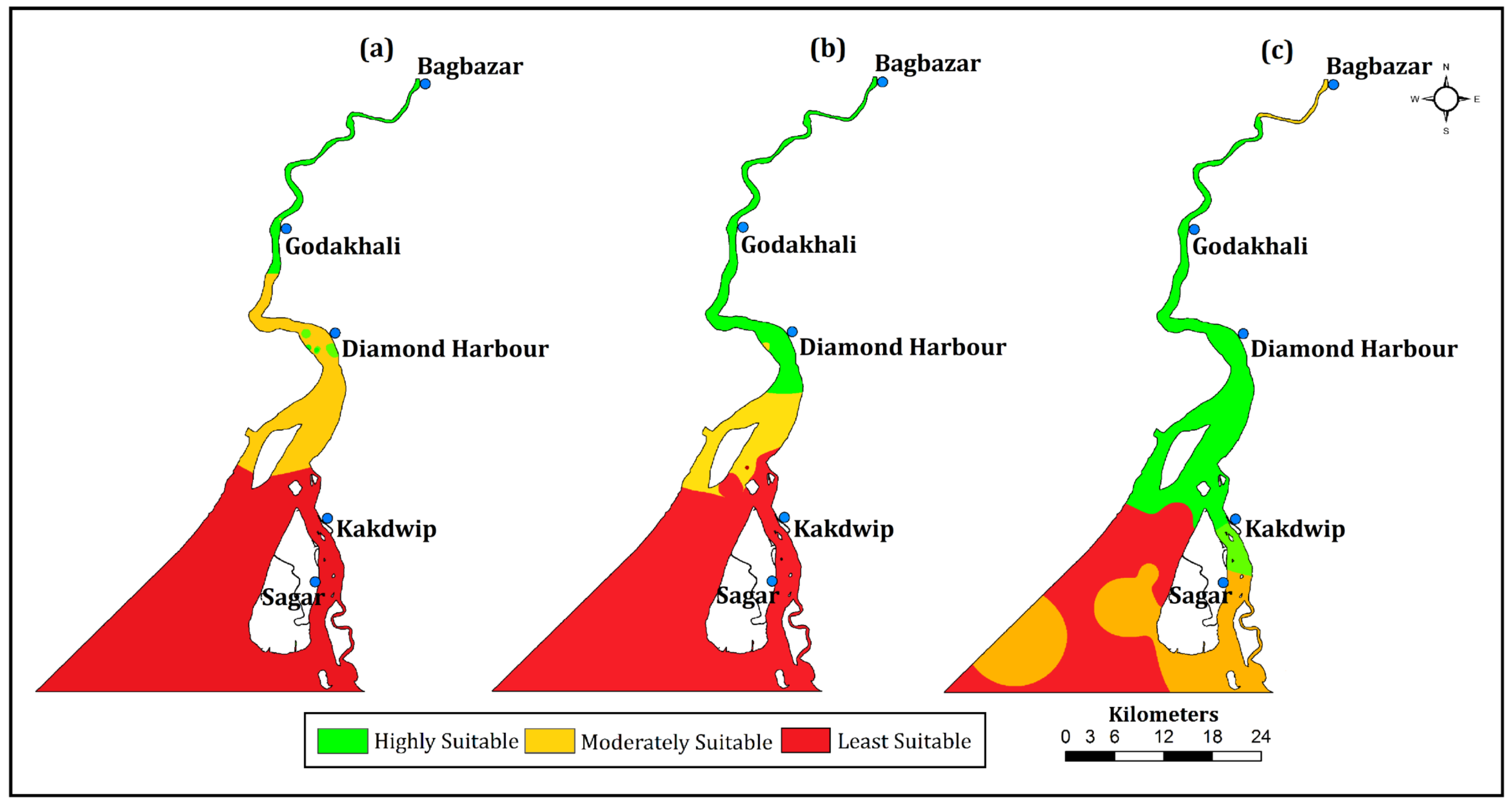
- This investigation characterized the relationship between the occurrence of juvenile Hilsa and six bio-geochemical parameters (water temperature, chlorophyll-a, turbidity, salinity, dissolved oxygen, and pH) in the lower stretch of Hugli river.

- This relationship helped us in determining the ranges of each biogeochemical parameter for different suitability criteria in three seasons (pre-monsoon, monsoon, and post-monsoon).

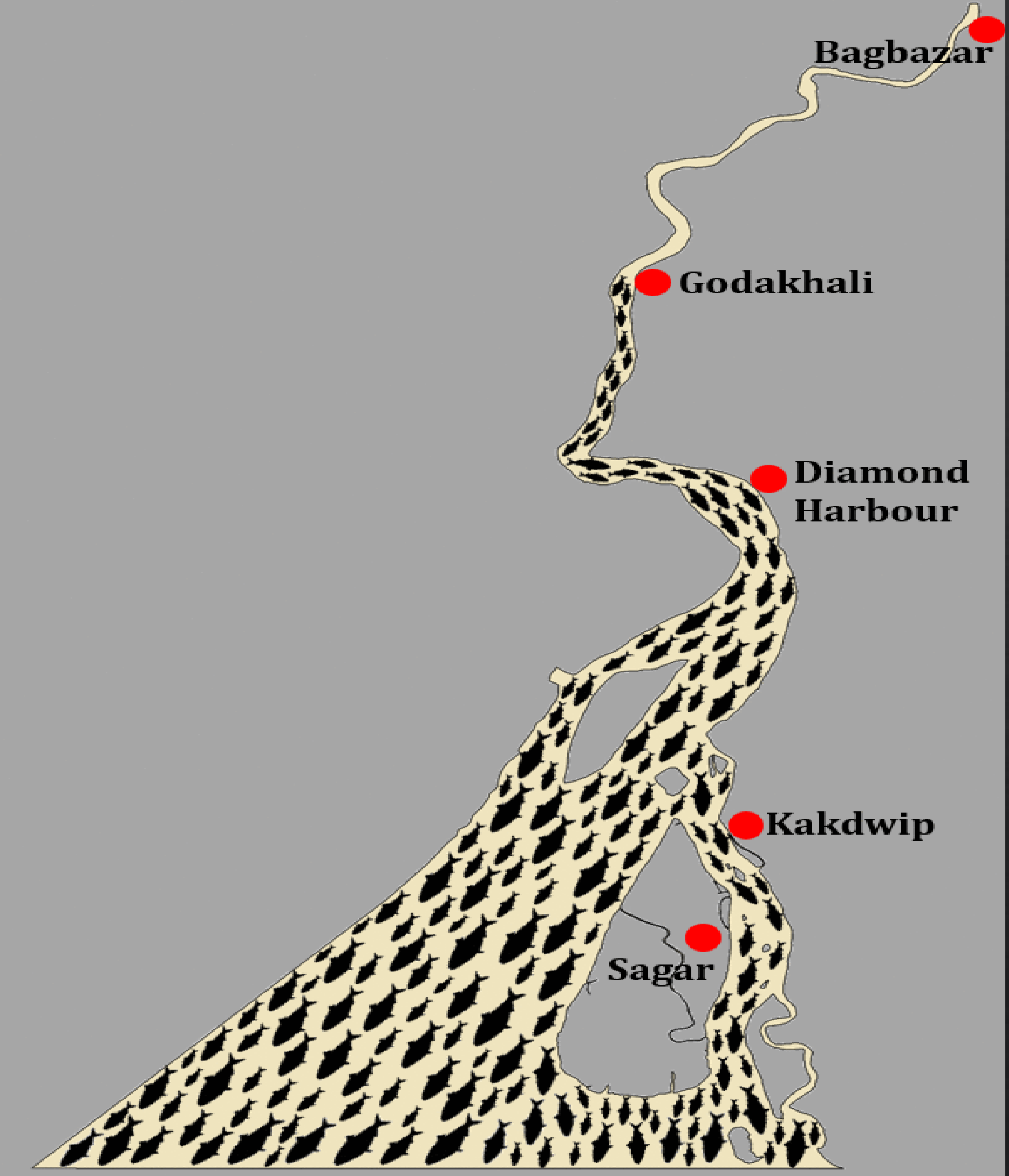
- Biogeochemical data were reclassified as per the suitability criteria and integrated into GIS-based modeling by a multi-criteria decision-making technique (analytical hierarchy process) to generate the habitat suitability maps for juvenile Hilsa

Suitability range of biogeochemical parameters in the three different seasons for juvenile Hilsa in the Hugli River estuary

Season	Parameters	Least suitable (1)	Moderately suitable (2)	Highly suitable (3)
Pre-monsoon	Water temperature (°C)	22.36–24.67	24.68–29.7	29.8–30.45
	Chlorophyll-*a* (mg m^{-3})	2.13–2.36	2.37–2.99	3.0–3.86
	Turbidity (NTU)	64–98	99–159	160–270
	Salinity (ppt)	5.47–17.60	1.91–5.46	0.7–1.9
	DO (mg/l)	4.87–5.38	5.39–5.66	5.67–6.15
	pH	8.13–8.26	7.97–8.12	7.82–7.96
Monsoon	Water temperature (°C)	29.6–30.01	30.02–30.27	30.28–31.29
	Chlorophyll-*a* (mg m^{-3})	1.20–2.19	2.20–2.59	2.60–3.37
	Turbidity (NTU)	391–415	281–390	120–280
	Salinity (ppt)	3.66–8.38	1.80–3.65	0.05–1.7
	DO (mg/l)	5.14–5.20	5.21–5.46	5.47–6.35
	pH	7.74–7.78	8.01–8.10	7.79–8.0
Post-monsoon	Water temperature (°C)	21.26–21.24	21.35–23.99	24–24.36
	Chlorophyll-*a* (mg m^{-3})	2.74–2.96	2.97–3.71	3.72–4.26
	Turbidity (NTU)	166–299	64–99	100–165
	Salinity (ppt)	12.1–14.5	7.26–12.0	0.11–7.25
	DO (mg/l)	5.60–5.86	5.87–6.26	6.27–6.75
	pH	7.81–7.86	8.01–8.16	7.87–8.0



Habitat suitability maps of juvenile Hilsa in the Hugli River estuary for three different seasons --- (a) Pre-monsoon (b) Monsoon (c) Post-monsoon



Role of tide and lunar phase on the juvenile Hilsa migration

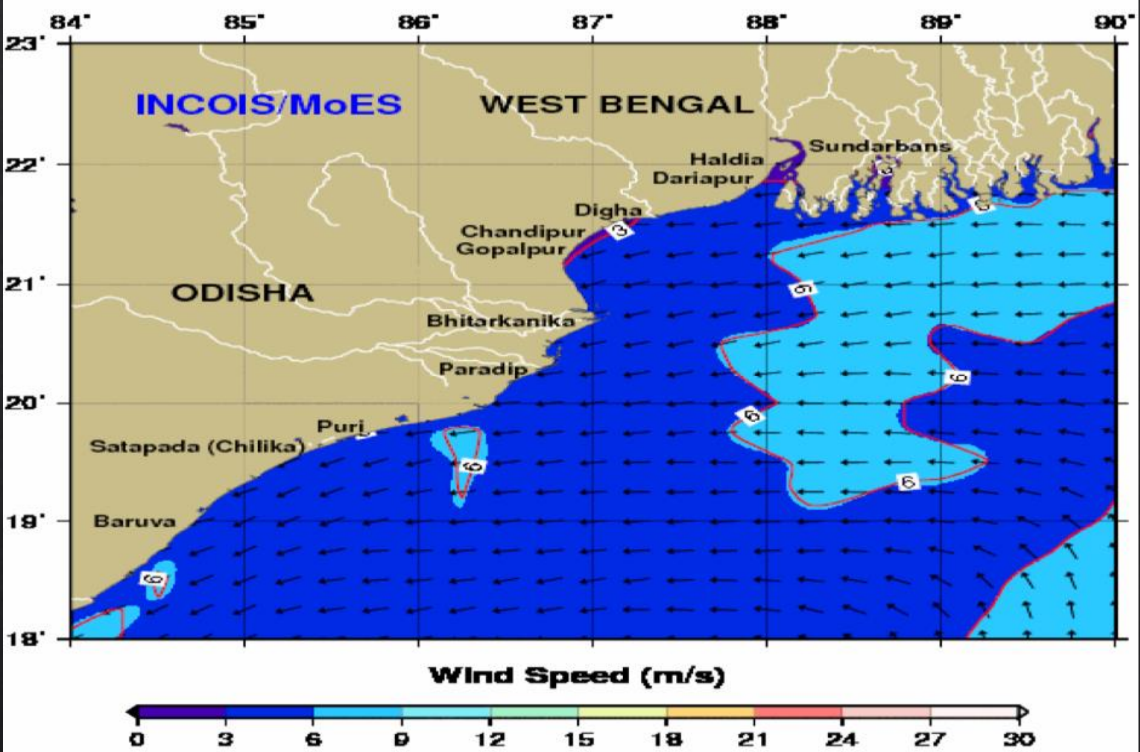
- The number of juvenile Hilsa were found to be much higher during low tides in most of the observations and there was a significant difference ($t = 11.904$, $P < 0.001$) between the high tide and low tide catches in the entire study region.

- Among the eight lunar phases, the number of juveniles was also observed to be higher during the new moon and full moon

Source: Giri, S., Chanda, A., Maity, S., Chakraborty, K., & Hazra, S. (2022). Role of tide and lunar phases on the migration pattern of juvenile Hilsa shad (*Tenualosa ilisha*) within a meso-macrotidal estuary. *Journal of Fish Biology*, *100*(4), 988-996.

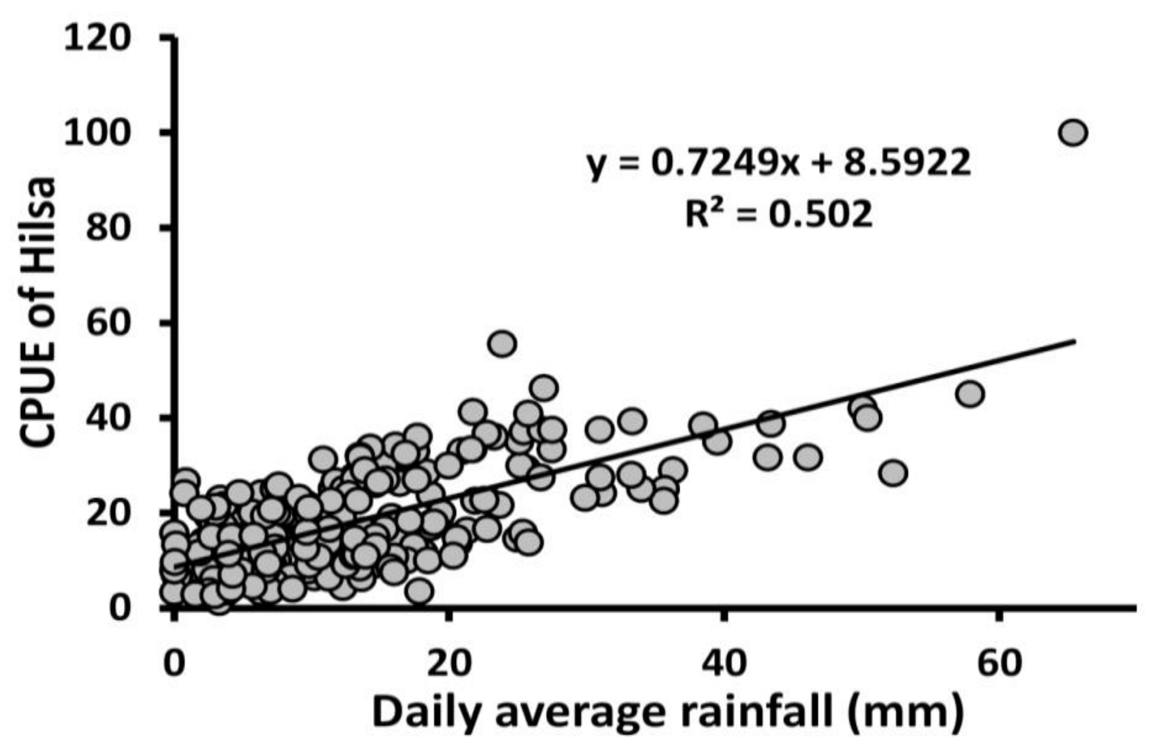
Case study – 2: Prediction of daily Hilsa catch in Hugli Estuary Using Lunar Phases, Rainfall and Wind

Effect of Wind direction on Hilsa catch



Ocean State Forecast map of INCOIS showing how the South-West monsoonal wind changes its direction towards west in the Bay of Bengal

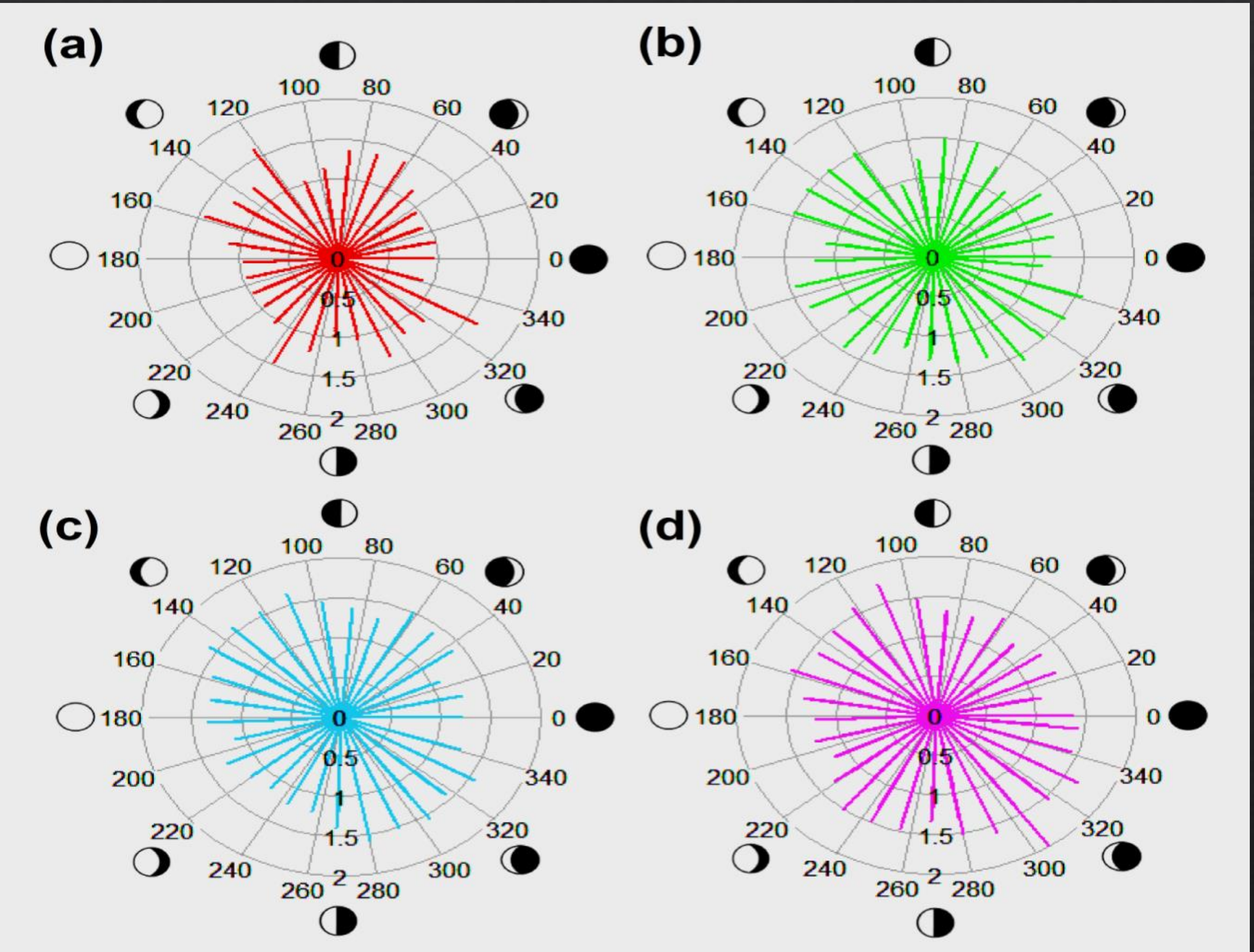
Relation between Rainfall & Hilsa catch

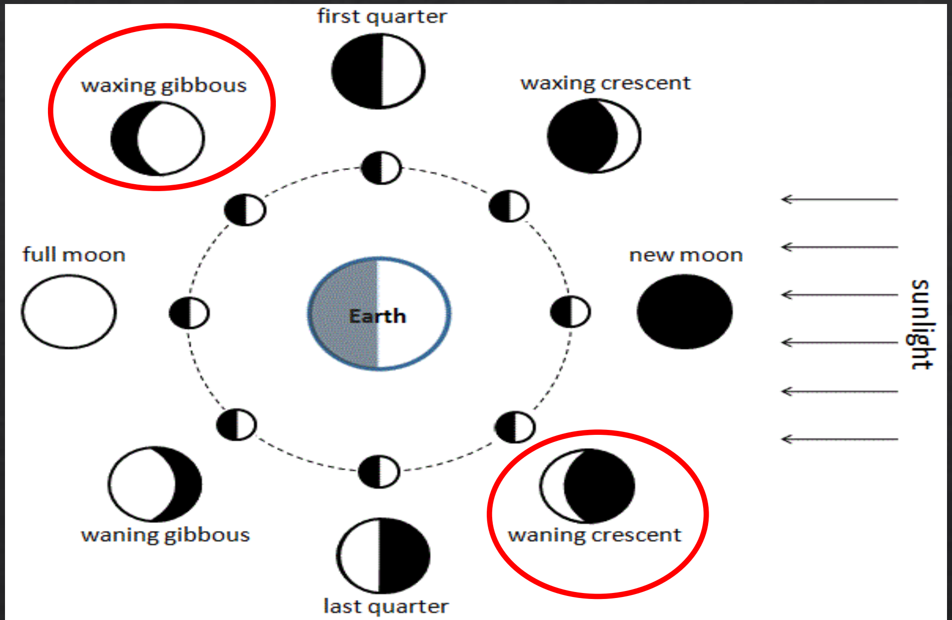


When CPUE of Hilsa was plotted against daily average rainfall, a positive and significant relationship was observed.

Source: Giri, S., Hazra, S., Ghosh, P., Ghosh, A., Das, S., Chanda, A., ... & Maity, S. (2019). Role of lunar phases, rainfall, and wind in predicting Hilsa shad (*Tenualosa ilisha*) catch in the northern Bay of Bengal. *Fisheries Oceanography*, *28*(5), 567-575.

Effect of Lunar periods on Hilsa catch





Polar plot between the log-transformed CPUE of Hilsa and lunar day of four months – (a) June (b) July (c) August (d) September

Research Approach

- Daily Hilsa catch data from June – September (during monsoon) of the four consecutive years 2013 – 2016 were collected from the five fishing boats.

- In order to standardize the CPUE computation only the fish catch data between 0800 h and 1600 h were considered. Out of these four years, data from 2013 – 2015 were used for developing the model (training data set) and data of 2016 were used for the validation of the model as the unknown data set.

- Daily rainfall data covering entire South Bengal were procured from India Meteorological Department (IMD), Alipore.

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- Wind velocity and direction were measured onboard using weather station (La Crosse Technology, WS-2350). Mean wind velocity and predominant wind direction during 8 h hauling were considered.

- 8 lunar phases were used as categorical variable in the model to detect the effect of specific lunar phase on Hilsa catch.

- Wind direction was used as the circular independent variable.

- Generalized Least Square (GLS) model was used to develop the empirical relation.

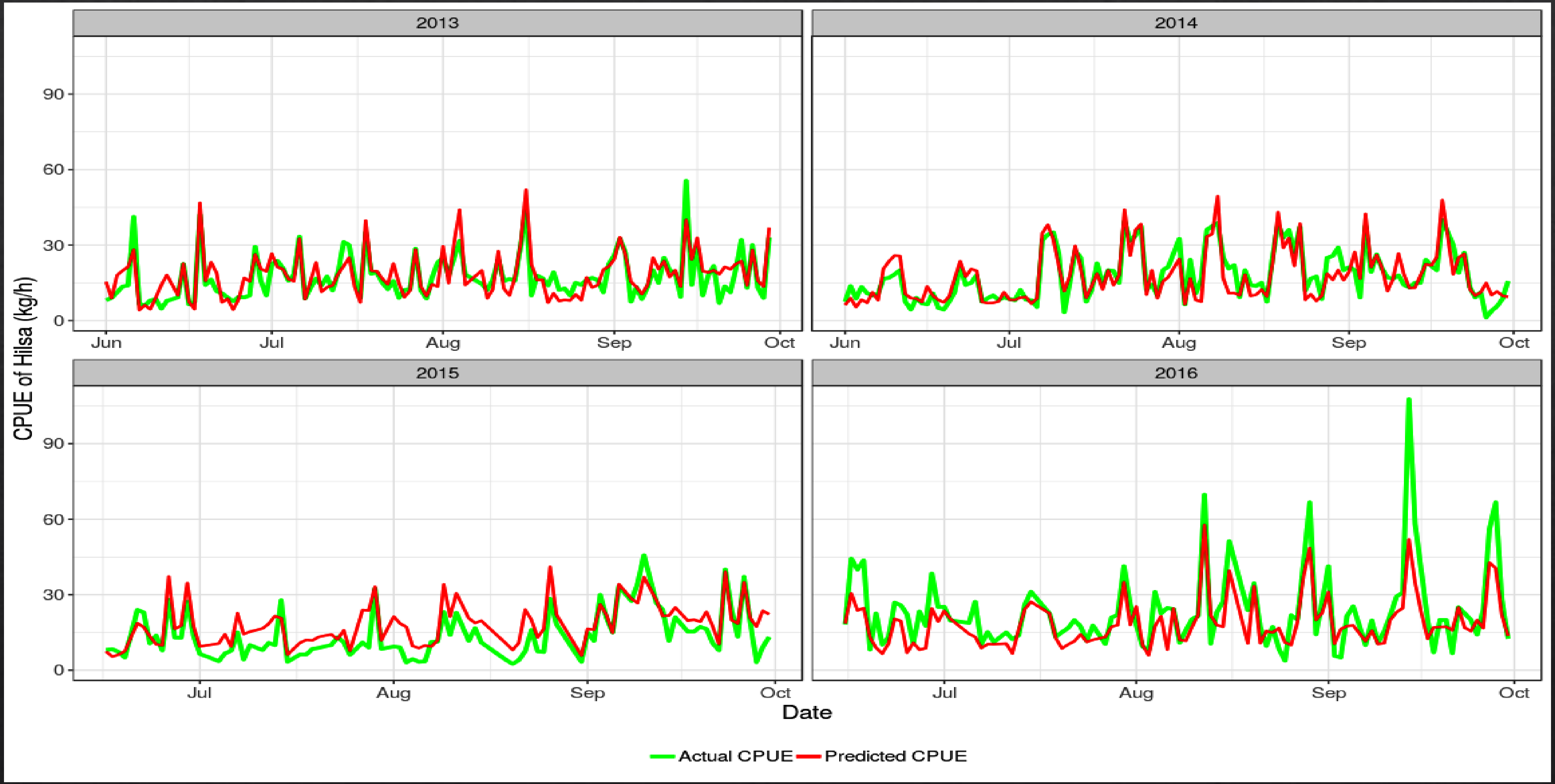
Key findings

- Out of the eight lunar phases, two lunar phases, waning crescent and waxing gibbous, showed significant positive correlation (coefficient value = 0.5677 & 0.7317; P = 0.0002 & <0.0001) with Hilsa CPUE.

- Rainfall (coefficient value = 0.4184) and wind direction exhibited significant positive correlation (P< 0.0001) with Hilsa CPUE.

- Wind from eastern side [‘sine’ component of the wind direction] also exhibited significant positive (coefficient value = 0.3112; P<0.0001) correlation with Hilsa CPUE. This has corroborated the traditional belief of the fishermen on the effect of easterly breeze on Hilsa catch.

Result validation



Comparison of actual CPUE values with predicted CPUE values for the monsoon months of the four years (2013-2016). Hilsa catch data from 2013-2015 were used as training dataset and 2016 catch data were used as validation dataset. Model predicted CPUE underestimated the actual CPUE in 2016 by 20%.

Research towards developing Oil Sardine advisory for Kerala coast

General Characteristics of Oil Sardine

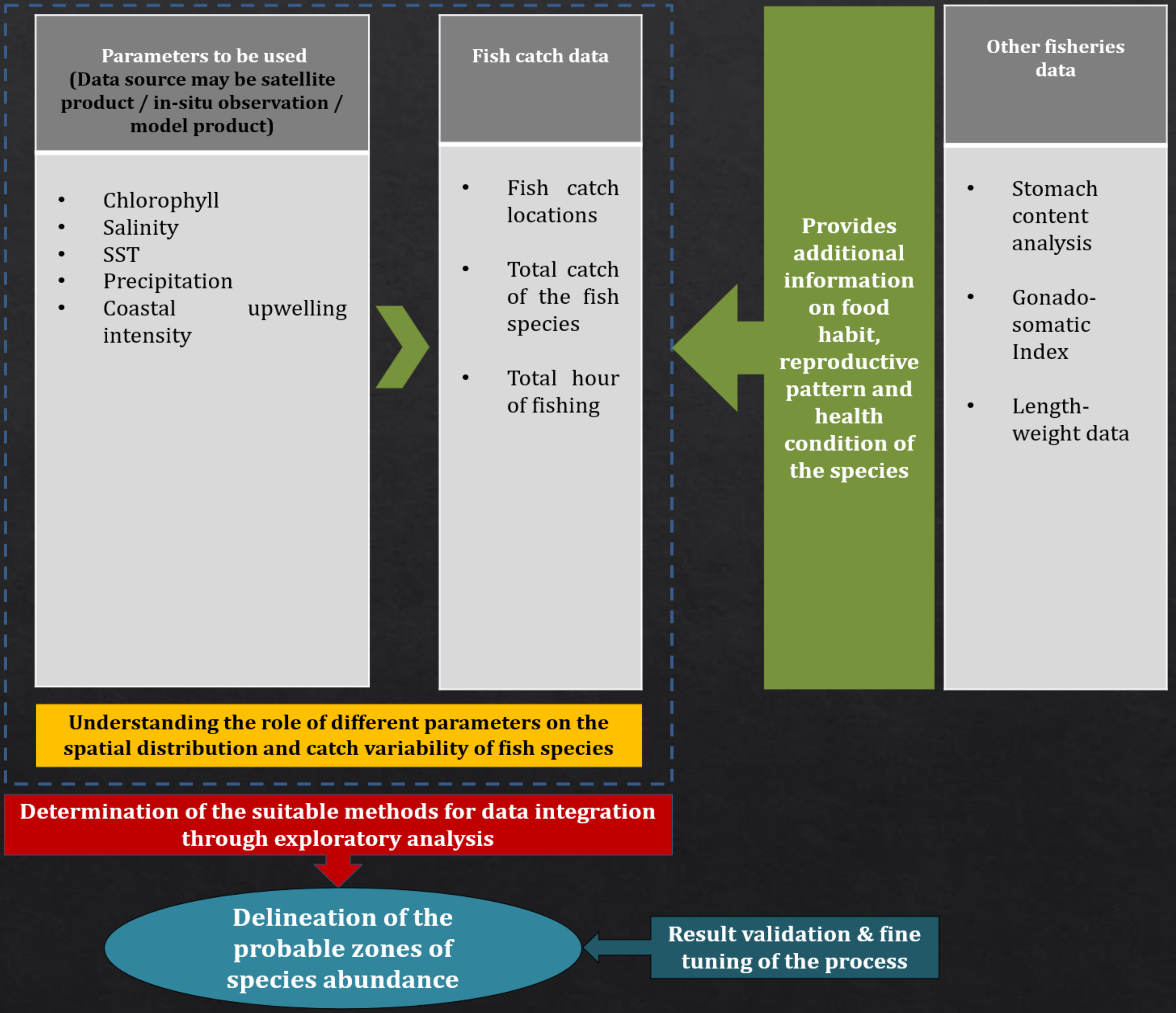
- The fish is a plankton feeder and mainly feeds on diatoms. However, dinoflagellates, and zooplanktons are also observed in the food items.

- Among diatoms, *Fragilaria oceanica* is considered the most preferred food item and considered the indicative species for oil sardine abundance. Dinoflagellates like *Procentrum*, *Ceratium*, and *Peridinium* and among zooplanktons *Acrocalanus*, *Paracalanus*, *Oithona*, Harpacticoids, *Lucifer*, and larval polychaetes were also reported in the stomach content.

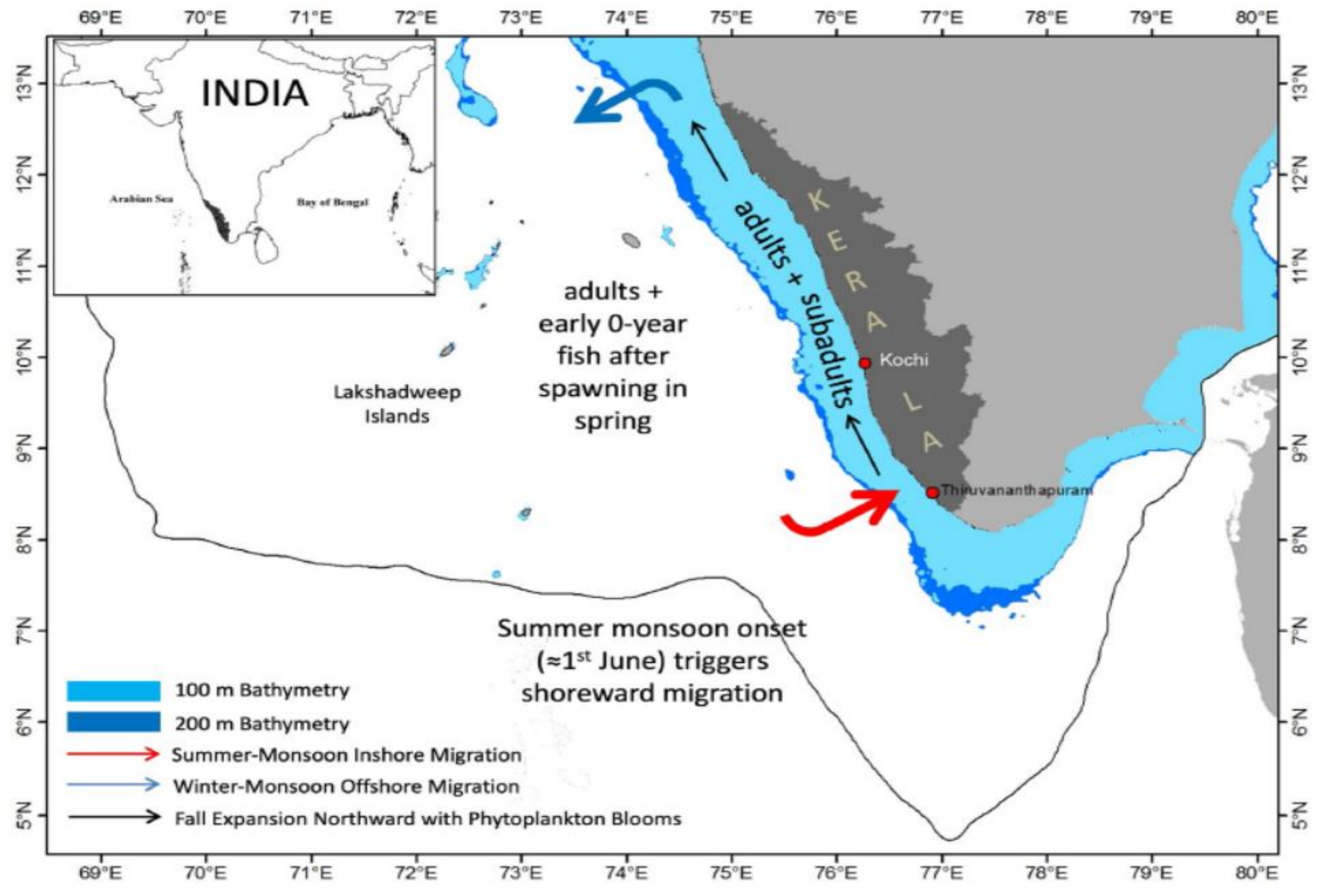
- The fish grows very rapidly and the peak spawning period is from May to August coinciding with the southwest monsoon.

- The fish shows a short offshore to coastal migration for spawning and feeding.

Conceptual framework for Oil Sardine habitat suitability analysis and development of experimental Oil Sardine advisory



Case study: Indian Oil Sardine landing forecast using environmental covariates



Source: Holmes, E. E., BR, S., Nimit, K., Maity, S., Checkley Jr, D. M., Wells, M. L., & Trainer, V. L. (2021). Improving landings forecasts using environmental covariates: A case study on the Indian oil sardine (Sardinella longiceps). *Fisheries Oceanography*, *30*(6), 623-642.

Research Approach

- In that study, Oil sardine landing was forecasted using generalized additive model (GAM) by incorporating the environmental covariates such as precipitation, upwelling intensity, Chlorophyll-a concentration and Sea Surface Temperature (SST).

- Out of these covariates, two covariates such as multiyear average regional SST and the monsoon rainfall over land improved both the model fit and out-of-sample prediction.

Yellowfin Tuna Fishery advisory

General Characteristics of Yellowfin Tuna

- Yellowfin Tuna (YFT) is a completely oceanic fish species and distributed across the tropical and sub-tropical seas.

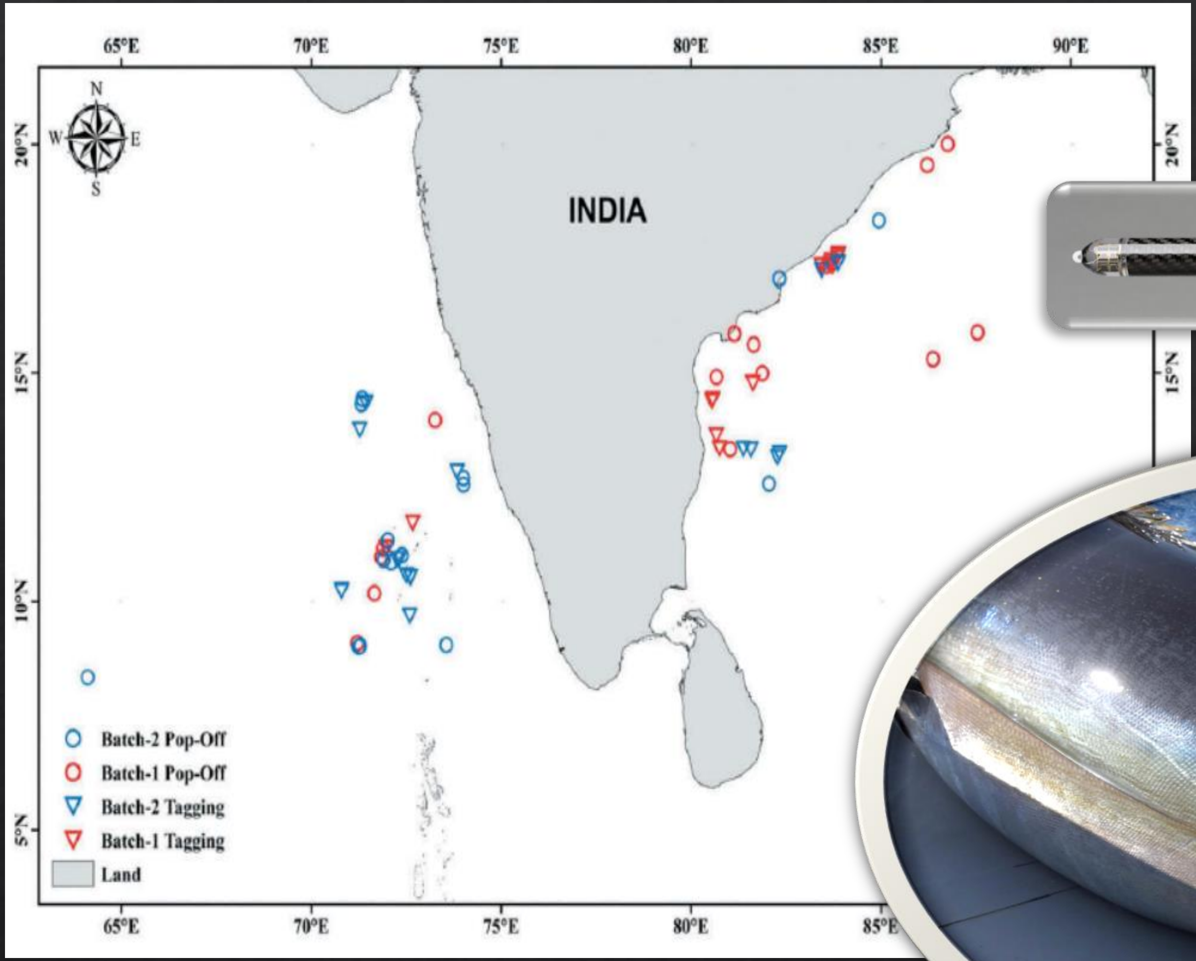
- The species is pelagic in nature and always move in a school.

- YFT mainly feed on fishes, crustaceans and squids..

- It is sensitive to the low dissolved oxygen concentration of the ambient water.

- Peak spawning period is observed during summer at the higher latitudes. However, year-round spawning is also observed in lower latitudes.

Case study: Yellowfin Tuna tagging for understanding habitat preference



- Yellowfin Tuna tagging experiments were conducted using Pop-up Satellite Archival Tags (PSATs) in both ARS and BoB.
- A total of 42 YFT were tagged in two batches during 2011–2014 in the Indian Seas.
- Tags were deployed in collaboration with Central Marine Fisheries Research Institute (CMFRI) and Fisheries Survey of India (FSI)

Source: Nimit, K., Masuluri, N. K., Berger, A. M., Bright, R. P., Prakash, S., TVS, U., ... & Varghese, S. P. (2020). Oceanographic preferences of yellowfin tuna (Thunnus albacares) in warm stratified oceans: A remote sensing approach. *International Journal of Remote Sensing*, *41*(15), 5785-5805.

Major observations

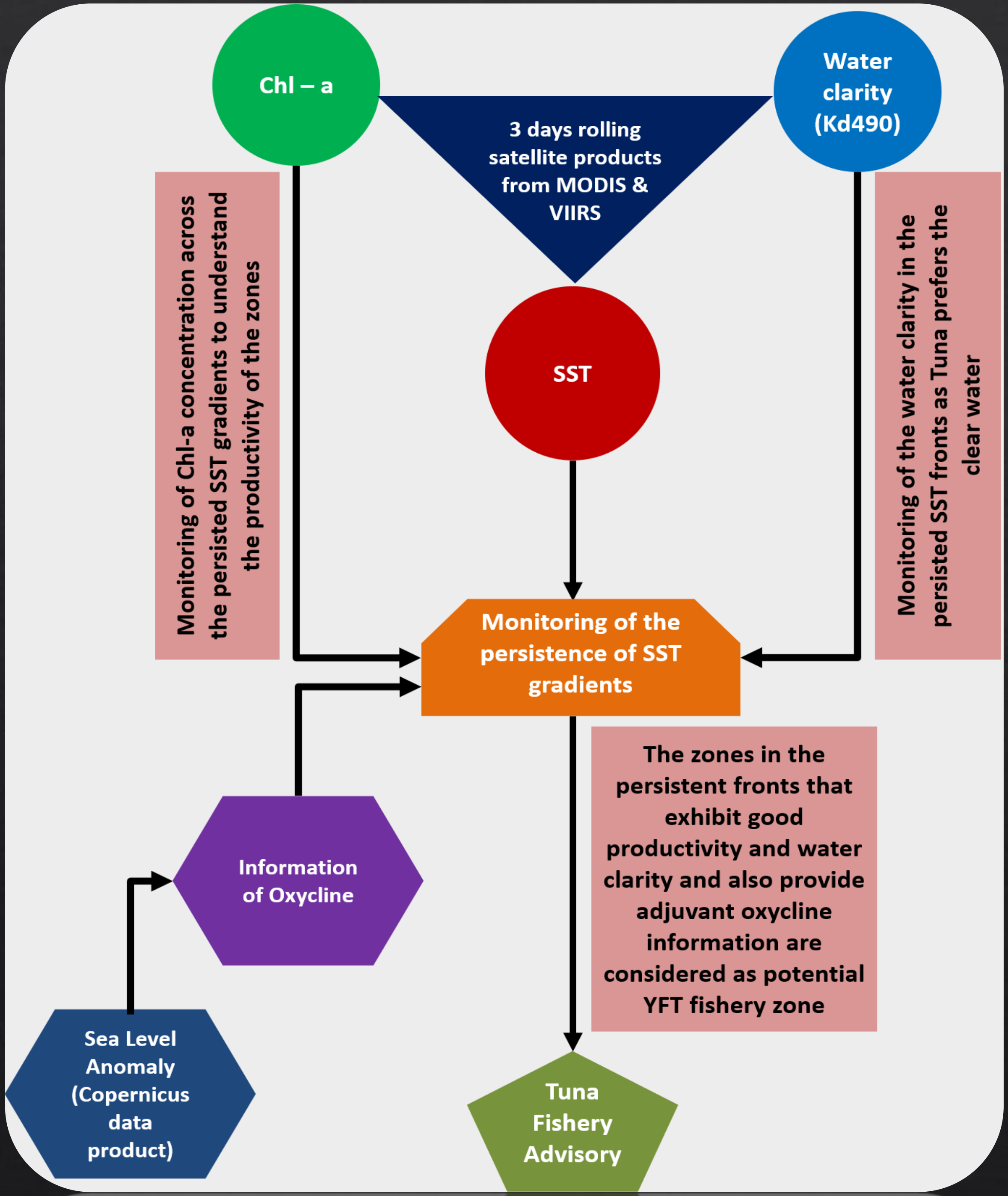
- Yellowfin tunas preferred (~90% of observations) temperatures between 26°C and 30°C in the Arabian Sea, whereas in the Bay of Bengal temperatures ranged between 25°C and 29°C (~90% of observations).

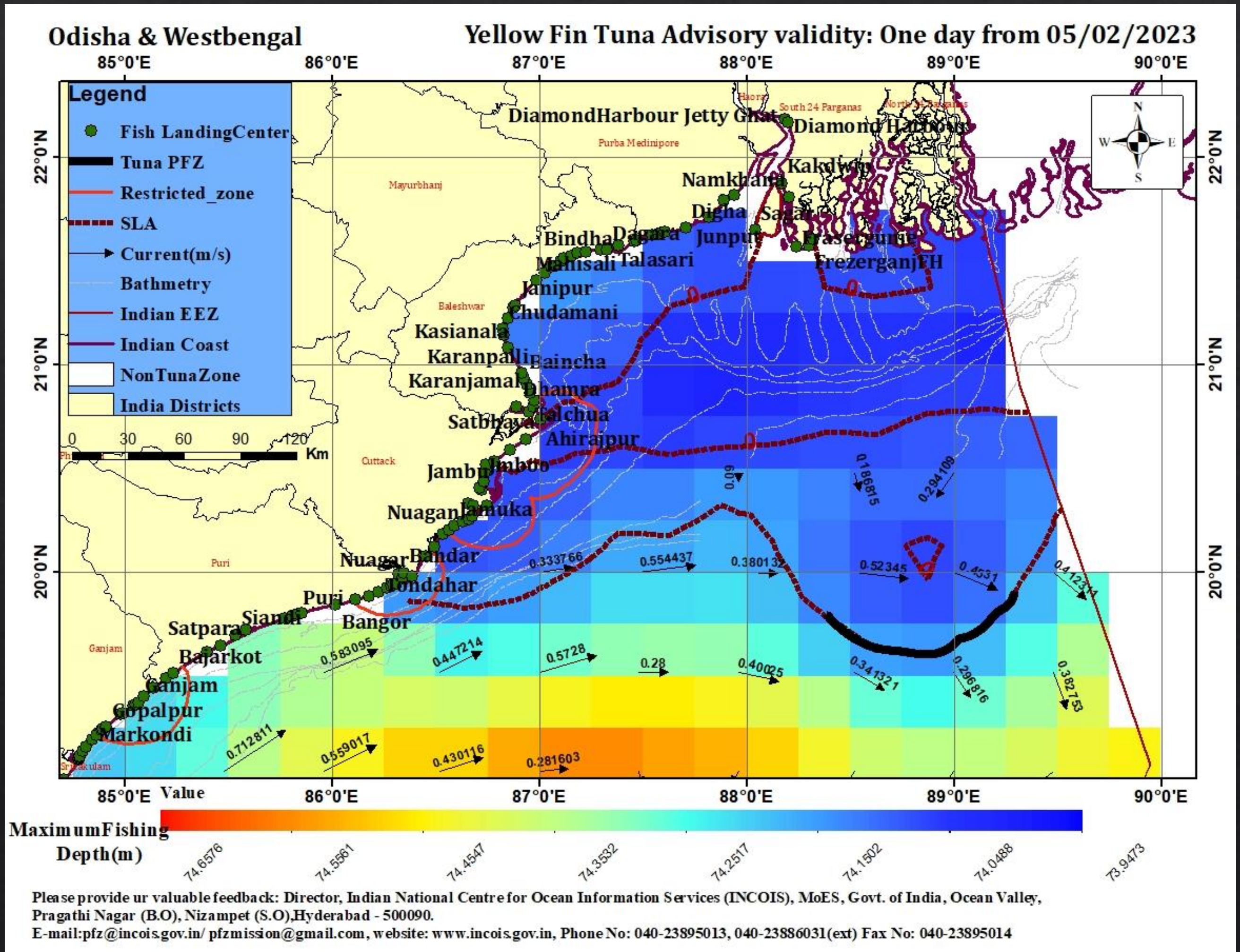
- The cumulative frequency for all depth records showed that 90% were between the surface to 100 m depth.

- Movement of tagged YFT with reference to SSHa shows that these fish tend to spend more time (70%) along the periphery of divergence zones (between ±6cm SSHa).

- Tagged individuals did not exhibit significant deep diving and avoided moving below the relatively shallow oxycline depth which indicates that the low dissolved oxygen levels are likely a limiting factor for tuna movement given their high oxygen demand

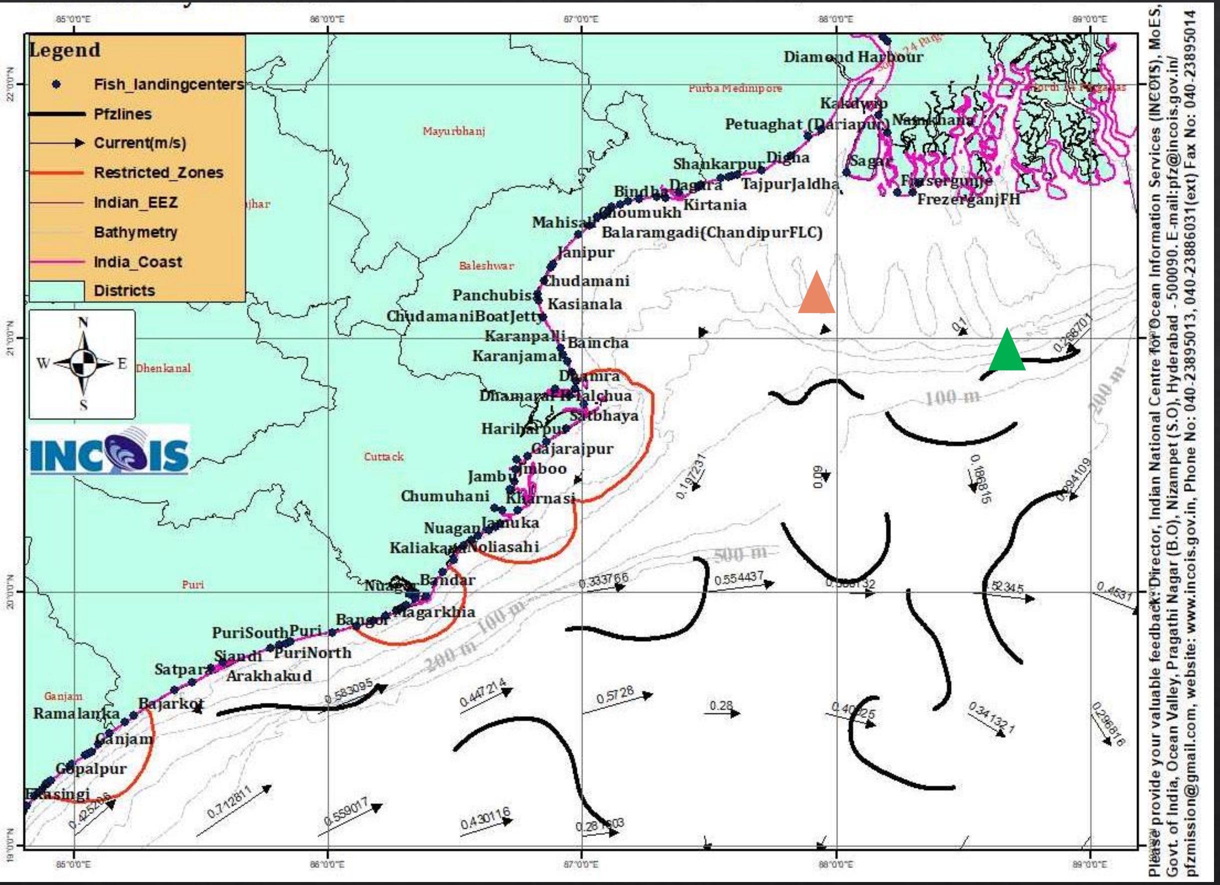
Schematic diagram showing how the INCOIS Yellowfin Tuna Advisory is generated





Strategies for PFZ validation

PFZ validation and cost-benefit analysis



Fishing at PFZ

Fishing at Non-PFZ

Details	PFZ	Non-PFZ
Name of the boat	MV Bramhanee Maa	MV Tarini Maa
Type of the gear	Gill net	Gill net
Duration of the total trip	1 day	1 day
Number of fishing hour	04	04
Number of hauls	01	01
Number of fishermen engaged	09	11
Total catch (Kg)	280	160
Major species caught	Hilsa, Sardine	Hilsa, Sardine
Approximate cost of the total catch (Rs)	110000/-	60800/-
Total expenditure in fishing operation (Rs)	32000/-	38000/-
Net profit (Rs)	78000/-	22800/-


THANK YOU