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Hilsa Fishery Advisory (HiFA) for West Bengal - "Development and Operationalization"

By

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11. Abstract

Indian National Centre for Ocean Information Services (INCOIS) has developed a method to generate species-specific fisheries advisory on Hilsa (*Tenualosa ilisha)* for the coastal waters of West Bengal. The advisories are generated using a machine-learning (ML) algorithm *viz*. Extreme Gradient Boosting (XGBoost). For developing the spatial prediction technique, georeferenced Hilsa catch per unit effort (CPUE) was used as a function of environmental variables like sea surface salinity (SSS), sea surface temperature (SST), surface current speed, and direction. The model was developed using the dataset for the monsoon season (June-September) for the period of 2012-2016. Using the trained model, daily maps of Hilsa availability potential were predicted for the monsoon season of 2021, 2022, and 2023 and validated against the observed catches of those respective days. Validation revealed around 70%-72% accuracy of the model predictions.

12. Keywords: CPUE, Hilsa, machine learning, model, West Bengal coastal water, spatial prediction.

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1. Background

Tenualosa ilisha (Hilsa shad) is a highly valued anadromous fish species in the Indo-Pacific, with nearly 90% of India's Hilsa catch coming from the Hooghly estuary and adjacent western Bay of Bengal. This fishery is vital for the livelihoods of millions of coastal fishers (Ahsan et al., 2014; Sajina et al., 2020). The Indian National Centre for Ocean Information Services (INCOIS) provides Marine Fishery Advisory Servies (MFAS) and conducts R&D for validation of existing operational services and new services. As a part of MFAS, INCOIS has been issuing Potential Fishing Zone (PFZ) advisories for over a decade which have been proven successful in increasing the catch per unit effort (CPUE) and reducing the search time. However, conventional PFZs—based on SST and chlorophyll are ineffective for Hilsa, which do not feed during their breeding migration in coastal waters and estuarine zones, the peak fishing region. Responding to community demand, INCOIS undertook focused research and successfully developed a Hilsa-specific fishery advisory system for the West Bengal coast, aimed at supporting sustainable livelihoods.

2. Methodology for generating Hilsa fishery advisory

The research on the Hilsa fishery advisory development focuses on understanding the spatial variability of the Hilsa catch with respect to different environmental drivers that influence its anadromous migration and catch variability. A flow diagram of the entire methodology is illustrated as Fig. 1.

2.1. Fishery data

Daily geo-referenced Hilsa catch records from 2012 to 2016 were collected during routine operations of a GPS enabled, mechanized fishing boat near the Hooghly estuary and Indian Sundarbans. The vessel exclusively deployed 600 m × 12 m gill nets with mesh sizes <90 mm, in compliance with West Bengal government norms (Kolkata Gazette, 2013). Catch data were standardized as CPUE (kg h^{-1}), considering fishing hours between 0500 and 1700 hrs (Giri et al., 2019). Only monsoon-season data (June–September) were analysed, yielding 546 days of CPUE records over five years.

2.2. Environmental data

Environmental variables influencing Hilsa migration primarily salinity, SST, and surface currents, were selected based on prior studies (Bhaumik, 2017; Hossain et al., 2016). Precipitation was excluded, as its influence is reflected through salinity changes. Corresponding daily datasets for salinity, SST, and current vectors (converted to speed and direction) were obtained from the GLORYS12V1 reanalysis product by CMEMS. This NEMO-based dataset incorporates in-situ assimilation via a reduced-order Kalman filter and 3D-VAR corrections, offering global coverage at 1/12° spatial and daily temporal resolution.

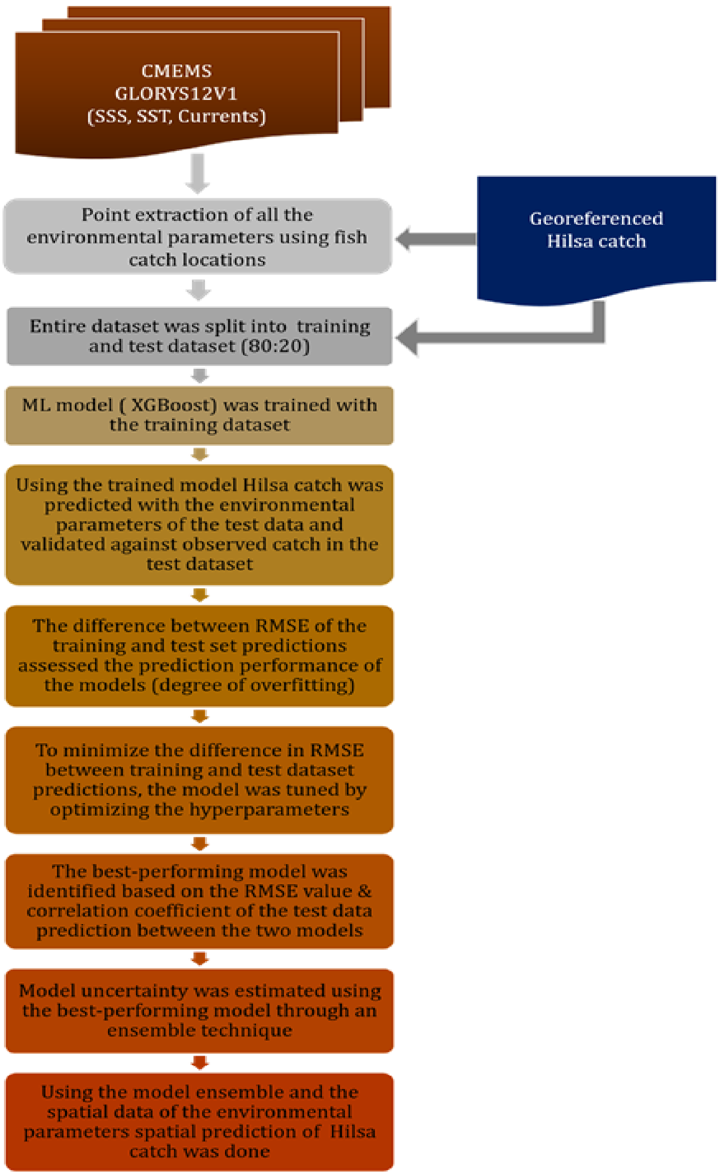

Fig. 1. Schematic diagram of the entire methodology involved in the development of HiFA

2.3. Advisory Domain

To support advisory generation during the peak Hilsa fishing period (June–September), daily averaged salinity, SST, and surface current data were extracted for the years 2012–2016. The spatial extent of analysis was limited to 20.5°N–21.75°N and 87.35°E–89.25°E. Current speed (m/s) and direction (°) were computed from u and v components using standard formulas. These derived variables, along with catch data, formed the input for machine learning modeling.

2.4. Model Selection

Multiple machine learning algorithms were evaluated, with XGBoost demonstrating superior performance for predicting Hilsa availability. The modeling approach, as described in Giri et al, 2025 (Plate. 1), was applied to develop the Hilsa Fishery Advisory (HiFA) for the West Bengal coast. HiFA classifies potential Hilsa availability into five categories: Very Low, Low, Medium, High, and Very High. Model accuracy was influenced by hyperparameter tuning, and the tested ranges and final optimized values for the XGBoost model are detailed in Table 1.

Table 1 Optimization range and final values of XGBoost hyper-parameters

Hyper-parameters	Optimization range	Optimized value
lambda	0.2 – 1.0	0.319052459911685
Alpha	0.2 – 3.0	0.510785541326811
Subsample	0.01 – 0.5	0.2540402444719459
Booster	gbtree, gblinear, dart	gbtree
colsample_bytree	0.1 – 1.0	0.8529998385578597
max_depth	10 – 500 (step = 1)	135
min_child_weight	1 – 50	2
learning_rate	0.001 – 0.2	0.06225471603495785
Gamma	0.1 – 1.0	0.7727393637625727
n_estimators	10 – 500 (step = 1)	47

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ORIGINAL ARTICLE

Short-Term Prediction of Hilsa (*Tenualosa ilisha*) Catch in the Northern Bay of Bengal Using Advanced Machine Learning Algorithms

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Keywords: CPUE | Hilsa | machine learning | modelling | northern Bay of Bengal | spatial prediction

ABSTRACT

Hilsa is a vital transboundary fishery resource in the Bay of Bengal (BoB), holding commercial, ecological, and cultural importance. This study aims to develop a short-term prediction of Hilsa catch in the northern BoB using a machine learning (ML) model. The prediction technique was developed considering the georeferenced Hilsa catch per unit effort (CPUE) as a function of environmental variables like surface salinity, sea surface temperature (SST), surface current speed, and direction. We employed two advanced ML algorithms, viz., random forest (RF) and 5. (XGBoost) to examine their efficacy in the short-term prediction of Hilsa for the northern BoB and compared the model performance with a baseline information obtained through multiple linear regression (MLR). Our analysis showed significant improvement in the prediction accuracy using advanced ML techniques where XGBoost again outperformed RF. The root mean square error (RMSE) values between observed and predicted CPUE for RF and XGBoost models were 5.72 and 5.63 kg/h, respectively. The correlation coefficient (r) between the observed and predicted catch were 0.90 and 0.93 for RF and XGBoost, respectively. SHapley Additive exPlanations (SHAP) analysis revealed the highest influence (58.38%) of surface current speed on the Hilsa CPUE. We generated the spatial prediction maps of Hilsa CPUE using the best performing (XGBoost) model with 85% prediction efficiency. This study showed the potential of the XGBoost model in developing a short-term prediction for Hilsa in the northern BoB, towards developing Hilsa fishery advisory for sustainable management of these fishery resources.

1 | Introduction

Hilsa, *Tenualosa ilisha* (Hamilton, 1822), is considered one of the most commercially important anadromous fish species in the entire Indo-Pacific region. The global distribution of Hilsa covers the marine, estuarine, and riverine systems in India, Bangladesh, Myanmar, Sri Lanka, Sumatra, Indonesia, Thailand, Vietnam, Pakistan, Kuwait, Oman, Qatar, Saudi Arabia, Iraq, and Iran (Ahsan et al. 2014; Freyhof 2014; Bhaumik 2017; Sahoo et al. 2018). However, the global Hilsa catch is primarily contributed by Bangladesh (50%–60%), followed by Myanmar (20%–25%) and India (15%–20%) (Majhi et al. 2023). Hilsa species connects different nations through its transboundary distribution, which has significant economic, cultural, and societal importance (Ahmed et al. 2021). As a single-species fishery, it provides a substantial livelihood for 0.5 million fishermen and 2.5 million people involved in the value chain and distribution in Bangladesh (Hossain

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Fisheries Oceanography, 2025; 0:e12746
https://doi.org/10.1111/fog.12746 1 of 16

Plate. 1. Screenshot of publication Giri et al, 2025. The details of the model development and validation can be accessed at https://doi.org/10.1111/fog.12746

3. Hilsa advisory with categorized catch and validation

The advisory maps are categorized into 'very low,' 'low,' 'medium,' 'high' and 'very high' for ease of understanding of the primary users. This categorization is based on the quartile distribution of the data used for model development. As the distribution of the data may differ for the four months (June-September), different limits have been set for the categories for the four different months. The range of the different categories for the four different months is presented in Table 2.

Table 2 Quartile distribution of catch data for four different months

Very Low | Low | Medium | High | Very High

	0%	20%	40%	60%	80%	100%
June	>0	8.30	10.74	16.36	90	>90
July	>0	10.00	14.17	23.00	95	>95
August	>0	12.64	18.00	27.74	90	>90
September	>0	13.00	18.00	27.00	88	>88

Based on this categorization, the 0th day prediction have been validated for the monsoon prediction months (June-September) for 2021, 2022, and 2023 and the validation matrices for each year has been prepared to understand the percentage accuracy of the prediction. The validation matrices are presented in Table 3, Table 4, and Table 5. A sample advisory map generated using the catch category is presented in Fig. 2.

Table 3 HiFA validation matrix for 2021

		Observed					Overall statistics
		VL	L	M	H	VH	
Predicted	VL	6	6				Year: 2021
	L	1	5	3			Total no. of predictions: 59
	M		2	10	2		Total no. of correct predictions: 43
	H			2	19		Prediction accuracy: 72.88%
	VH					3	

Table 4 HiFA validation matrix for 2022

		Observed					Overall statistics
Predicted		VL	L	M	H	VH	Year: 2022 Total no. of predictions: 94 Total no. of correct predictions: 66 Prediction accuracy: 70.21%
	VL	9	7				
	L	6	13	1			
	M	2	7	19	3		
	H			2	18		
	VH					7	

Table 5 HiFA validation matrix for 2023

		Observed					Overall statistics
Predicted		VL	L	M	H	VH	Year: 2023 Total no. of predictions: 98 Total no. of correct predictions: 71 Prediction accuracy: 72.44%
	VL	14	10	2			
	L	2	22	1			
	M		2	11	3		
	H			4	17		
	VH				3	7	

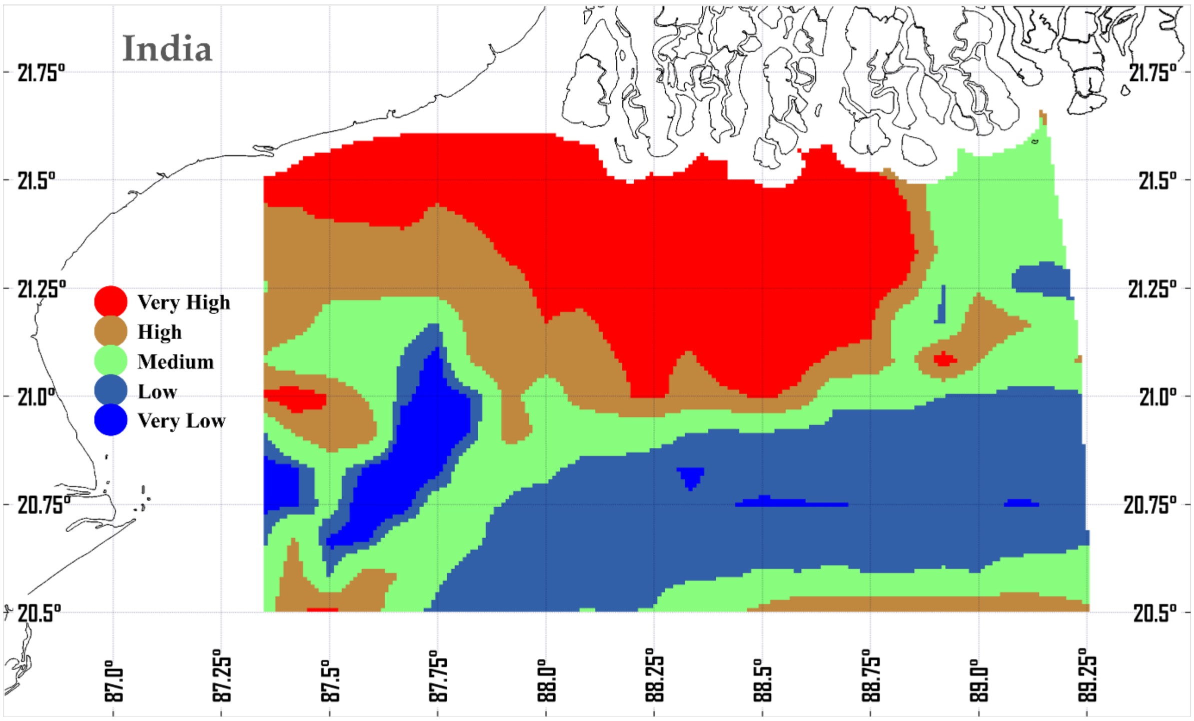


Fig. 2. Sample Hilsa advisory map with Hilsa availability potential categories

4. Limitation

The prediction model was developed with a smaller volume of available dataset. Despite that, reasonably good prediction efficiency of the model was obtained through hyperparameter tuning, even though the amount of data affects the performance of this kind of data-driven model.

Based on the existing validation report (Giri et al. 2025), there is good correlation between the predicted and observed Hilsa catch. Validation with the categorized catch data also reveals 70% – 72% of prediction accuracy. However, in the categorized maps, sometimes a large area may be categorized under a single category based on the data range for that category, which is under R&D and will be fixed in the updated version.

5. Operational Implementation

The operational configuration is implemented using Bash and Python hybrid script which performs the following main automated tasks:

Data download and Preprocessing: Downloads required input data invoking Command Line Interface (CLI) of Copernicus Marine Data Client and pre-processes the data for pre-trained model compatibility.

Model Execution: Runs an XGBoost-based prediction model to estimate Hilsa availability potential in five categories: 1: Very low, 2: Low, 3: Medium, 4: High and 5: Very High.

Output Generation: Saves the spatial distribution of Hilsa availability potential for the West Bengal coast in NetCDF format. The variable "category" ranges 1-5 indicating 'Very low' – 'Very High' potential.

House Keeping: Organizes files into daily directories, ensuring isolation from previous runs. Stores all inputs, intermediate files, and outputs within the designated daily directory. Notify low diskspace, execution status via email.

5.1. Environment & Libraries

HiFA has been set up in **HilsaOp** conda environment with Python 3.10.x. The required libraries installed in HilsaOP environment are listed in Table 6.

Table 6 Required Python libraries for HiFA

`aiosignal==1.3.2`	`joblib==1.4.2`	`qtpy==1.9.0`
`alembic==1.14.1`	`kiwisolver==1.4.8`	`s3transfer==0.11.1`
`async-timeout==4.0.3`	`mako==1.3.8`	`scikit-learn==1.3.2`
`boto3==1.36.2`	`matplotlib==3.10.0`	`scipy==1.10.0`
`botocore==1.36.2`	`multidict==6.1.0`	`semver==3.0.2`
`cachier==3.1.2`	`netcdf4==1.6.2`	`shapely==2.0.6`
`cartopy==0.24.1`	`numcodecs==0.13.1`	`sqlalchemy==2.0.37`
`cftime==1.6.4.post1`	`optuna==3.2.0`	`tenacity==9.0.0`
`colorlog==6.9.0`	`pillow==11.1.0`	`threadpoolctl==3.5.0`
`contourpy==1.3.1`	`plotly==5.15.0`	`tzdata==2024.2`
`copernicusmarine==1.3.2`	`portalocker==3.1.1`	`watchdog==6.0.0`
`cycler==0.12.1`	`propcache==0.2.1`	`xarray==2025.1.1`
`fonttools==4.55.4`	`pyparsing==3.2.1`	`xgboost==2.0.0`
`frozenlist==1.5.0`	`pyproj==3.4.1`	`xlrd==2.0.1`
`greenlet==3.1.1`	`pyshp==2.3.1`	`xlsxwriter==1.3.8`
`importlib-metadata==8.5.0`	`pystac==1.11.0`	`yarl==1.18.3`
	`pytz==2024.2`	`isort==5.8.0`

5.2. HiFA Process Flow

HiFA provides the Hilsa availability potential advisories daily during the peak season (June-September) excluding the local fishing ban Period for West Bengal coast. The Process flow diagram of HiFA illustrated in Fig. 3. The mother script for this process flow is "**HiFA_Mother_Script.bash**". It sets the environment, defines the path for all the sub-scripts, python scripts, supporting files, output, contains access credentials, mail lists and several processing switches. It controls the sequential process flow from data downloading to final product generation.

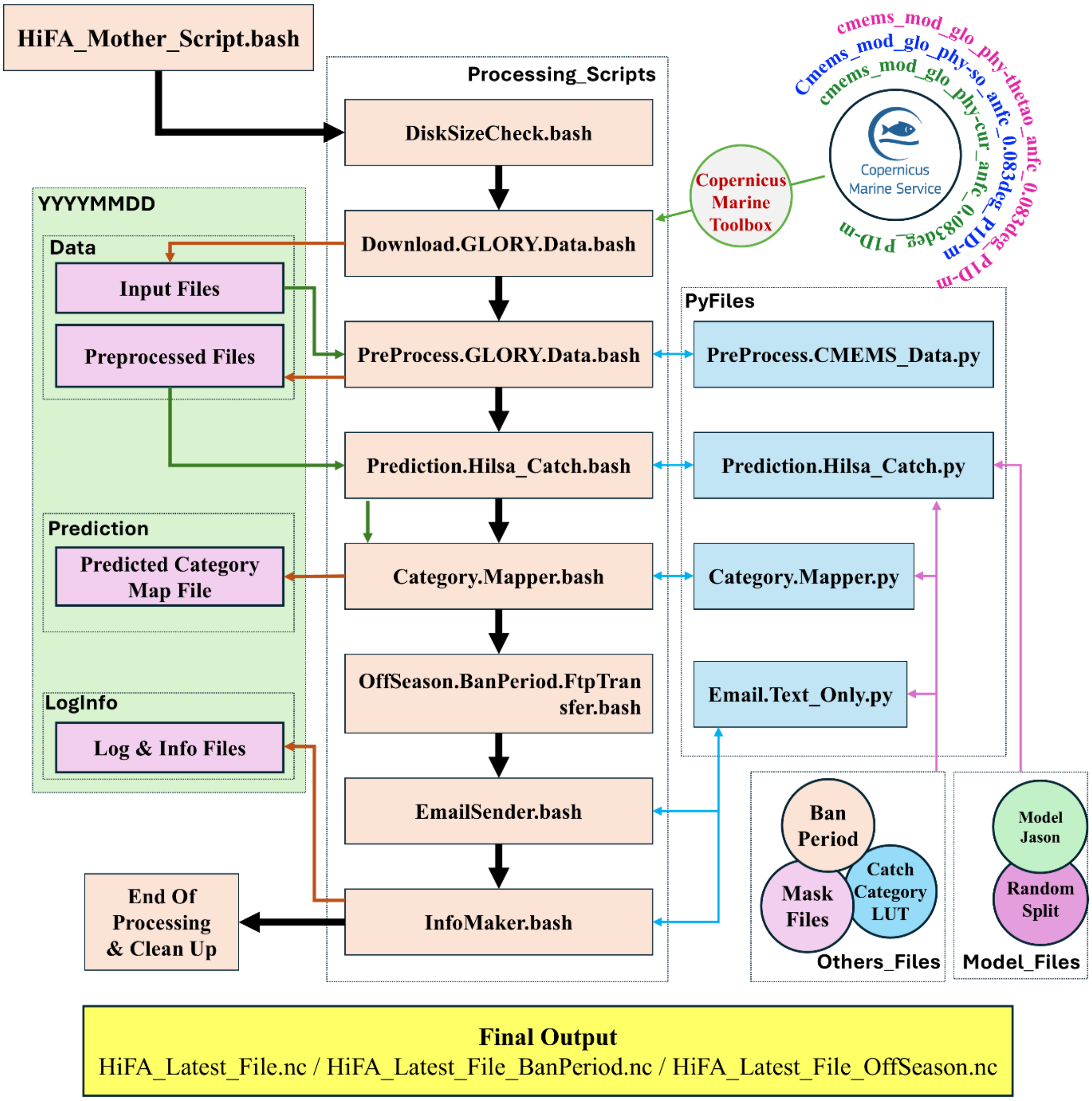


Fig. 3. Process flow diagram of HiFA

5.3. HiFA Directory Structure

The processing scripts consist of several bash files, py files, lookup tables, and mask files. The Main directory containing the files and folder is set as **`ScriptPath`**, in the main script (**HiFA_Mother_Script.bash**). The directory structure is maintained in a pattern so that these sub-scripts and supporting files are accessed multiple times in different steps. The output products are distributed in different directories for easy access. The script structure and the output directory structure are shown in Fig. 4 & Fig. 5, respectively.

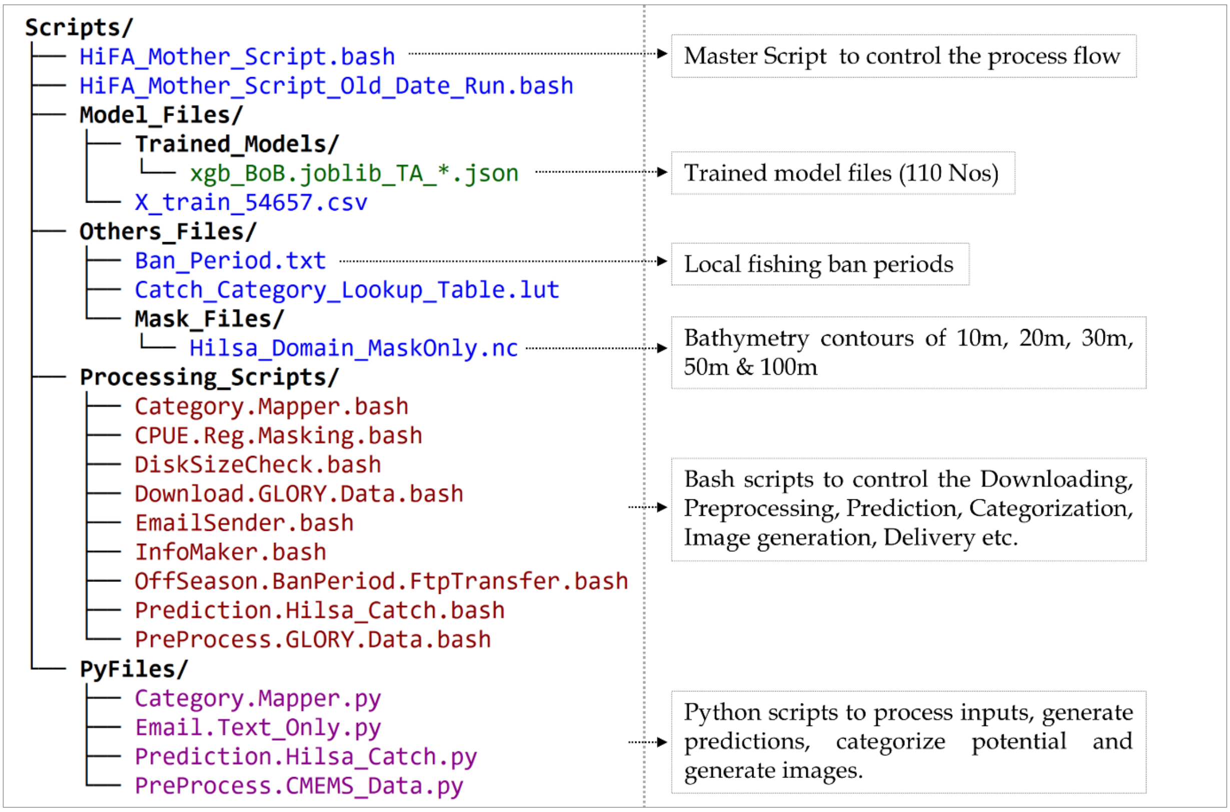


Fig. 4. Directory structure of the processing scripts.

```
Output/
├── YYYY/
│   └── YYYYMMDD/
│       ├── Data/
│       │   ├── YYYYMMDD_YYYYMMDD2_CMEMS_GLO_PHY_0.083deg_DailyMean.Current_Direction.P.nc
│       │   ├── YYYYMMDD_YYYYMMDD2_CMEMS_GLO_PHY_0.083deg_DailyMean.Currents.nc
│       │   ├── YYYYMMDD_YYYYMMDD2_CMEMS_GLO_PHY_0.083deg_DailyMean.Current_Speed.P.nc
│       │   ├── YYYYMMDD_YYYYMMDD2_CMEMS_GLO_PHY_0.083deg_DailyMean.Salinity.nc
│       │   ├── YYYYMMDD_YYYYMMDD2_CMEMS_GLO_PHY_0.083deg_DailyMean.Salinity.P.nc
│       │   ├── YYYYMMDD_YYYYMMDD2_CMEMS_GLO_PHY_0.083deg_DailyMean.Temperature.nc
│       │   └── YYYYMMDD_YYYYMMDD2_CMEMS_GLO_PHY_0.083deg_DailyMean.Temperature.P.nc
│       ├── LogInfo/
│       │   ├── YYYYMMDD_Run_Brief_Details.log
│       │   └── ProcessHiFA.log
│       └── Prediction/
│           └── HiFA_Latest_File.nc / HiFA_Latest_File_BanPeriod.nc / HiFA_Latest_File_OffSeason.nc
└── HiFA_Master_Time_Log
```

Fig. 5. Output product directory structure

5.4. Operational Execution

For the operational product generation, the mother script **"HiFA_Mother_Script.bash"** is executed in the using - `bash HiFA_Mother_Script.bash` or `source HiFA_Mother_Script.bash` in manual mode or the same can be invoked automatically using crontab. The `HiFA_Mother_Script.bash` retrieves the current date from the system and proceeds with the process flow. To generate products for an historical date, `HiFA_Mother_Script_Old_Date_Run.bash` needs to be invoked with the desired date as an argument in dd-mmm-yyyy format, for example, `source HiFA_Mother_Script_Old_Date_Run.bash 01-Sep-2024`

5.5. Output Data

The final output file **`HiFA_Latest_File.nc`** containing the spatial map of Hilsa availability potential is stored in **"`Prediction/`"** directory inside the data directory of the processing day (`YYYYMMDD`). The file contains two variables, **"category"** and **"category_name"**. the **"category"** variable contains the ID's of the category as 1=Very Low, 2=Low, 3=Medium, 4=High, 5=Very High. And the "category_name" variable contains the respective category name strings. The `ncdump -h HiFA_Latest_File.nc` result is shown in Fig. 6.

```
netcdf HiFA_Latest_File {
dimensions:
	lat = 222 ;
	lon = 334 ;
	time = 3 ;
variables:
	double lat(lat) ;
		lat:_FillValue = NaN ;
		lat:units = "degrees_north" ;
		lat:long_name = "latitude" ;
		lat:point_spacing = "even" ;
		lat:axis = "Y" ;
		lat:standard_name = "latitude" ;
	double lon(lon) ;
		lon:_FillValue = NaN ;
		lon:units = "degrees_east" ;
		lon:long_name = "longitude" ;
		lon:point_spacing = "even" ;
		lon:axis = "X" ;
		lon:standard_name = "longitude" ;
	double time(time) ;
		time:_FillValue = NaN ;
		time:axis = "T" ;
		time:standard_name = "time" ;
		time:units = "days since 2024-09-15" ;
		time:calendar = "proleptic_gregorian" ;
	double category(time, lat, lon) ;
		category:_FillValue = NaN ;
		category:long_name = "Predicted Hilsa Availability Potential Category ID" ;
		category:description = "The Category ID are 1=Very Low, 2=Low, 3=Medium, 4=High, 5=Very High" ;
		category:units = "none" ;
	string category_name(time, lat, lon) ;
		category_name:long_name = "Predicted Hilsa Availability Potential Category" ;
		category_name:units = "none" ;

// global attributes:
		:history = "Created on 2024-09-15 20:16:49" ;
		:Conventions = "CF-1.6" ;
		:title = "Predicted Hilsa Availability Potential" ;
		:source = "Generated By Hilsa Fishery Advisory (HiFA) Processing Chain of INCOIS, Hyderabad." ;
}
```

Fig. 6 Structure of the final NetCDF output

5.6. Quality Check

After the generation of the final output file, `HiFA_Latest_File.nc`, quality check of the file are carried out. The output file is visualized using a NetCDF visualization tool to check for potential issues before pushing it for dissemination. Subsequently it is ensured that the "**category**" variable of `HiFA_Latest_File.nc` must contains integer values ranging 1-5 for the valid region of interest. The output file does not pass QC if any of the following is observed

a) Nan values for the entire region of interest
b) Spurious values beyond the predefined range of 1-5, i. e. if it contains values <1 or >5
c) Almost entire region of interest is covered by High or Very High category, i.e. "category" values 4 & 5.

The maps of all the advisory dates present in the output file are verified for any such errors. An example of acceptable vs avoidable output is demonstrated in Fig. 7.

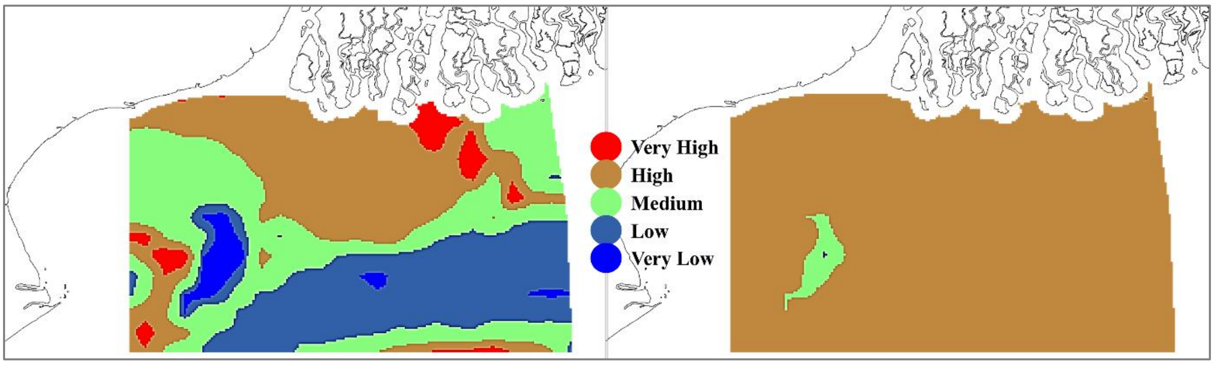


Fig. 7 Example of acceptable (left) and avoidable (right) patterns

5.7. Web Dissemination

The advisory is hosted at the GIS based INCOIS HiFA web portal. After the completion of the quality check, the final output data is pushed to designated WebFtp. The web-portal directly accesses the NetCDF file and updates the map. The sample screenshot of the INCOIS HiFA web-portal is shown in Fig. 8.

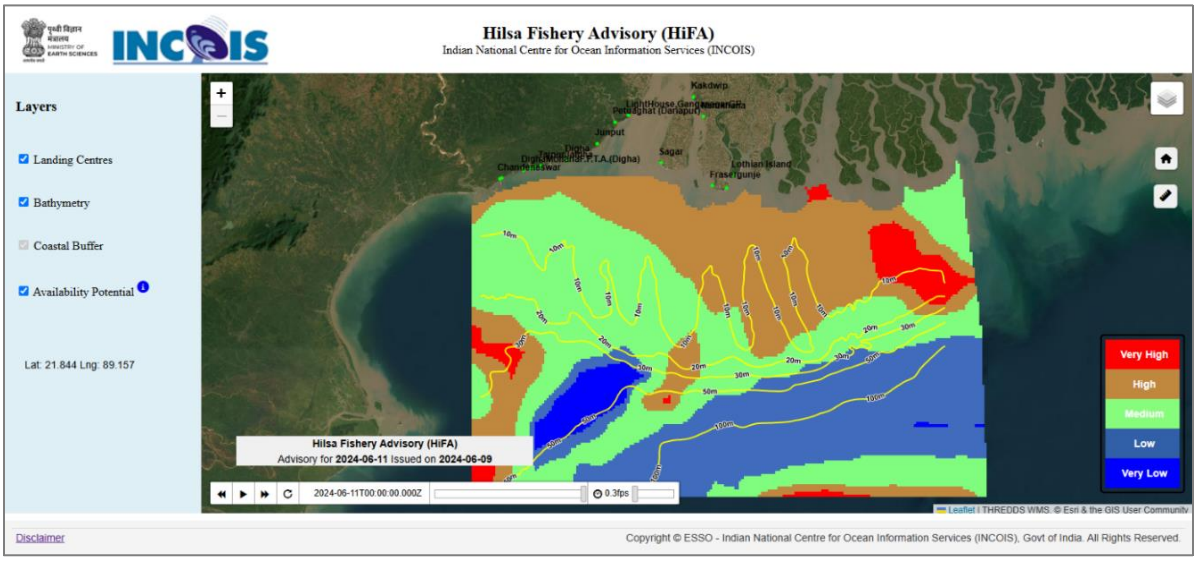


Fig. 8 sample screenshot of the INCOIS HiFA web-portal

5.8. Info & Log files

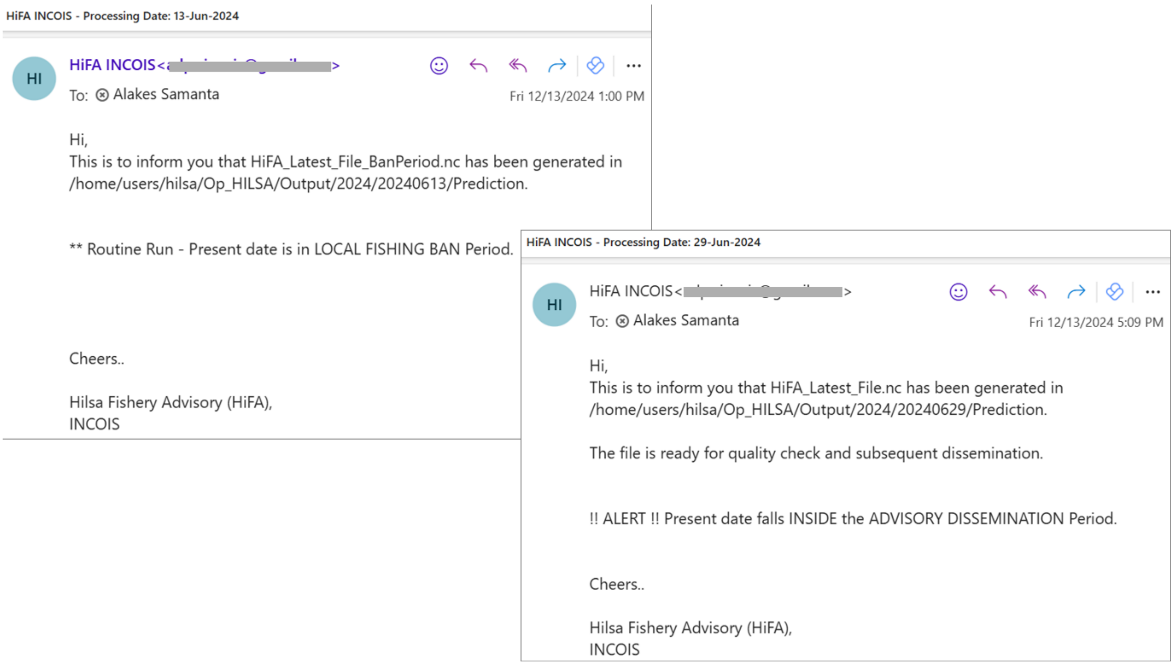
During execution, HiFA creates log files, tracks possible errors occurred, and keeps track of the important times such as execution initiation, completion of different steps and completion. The log files `YYYYMMDD_Run_Brief_Details.log` and `ProcessHiFA.log` containing brief and detailed execution information respectively and are stored in **"LogInfo/"** directory inside the data directory of the processing day (YYYYMMDD). The time log of all the independent executions is tabulated in the **"HiFA_Master_Time_Log"** file inside the master output directory.

5.9. Off Season Ban Period Handling

HiFA process flow is designed to take care of the execution originating in the Off season (October to May) and local fishing ban periods. The local fishing ban period information is tabulated in **Ban_Period.txt** in the **"Others_Files/"** directory to be fetched by the process control. The output generation is not restricted, however, the final output files name changes from **HiFA_Latest_File.nc** to **HiFA_Latest_File_OffSeason.nc** or **HiFA_Latest_File_BanPeriod.nc,** as per the scenario, and transfer of the file to WebFtp is denied. The notification email also contains this information.

5.10. Email Notification Integration

HiFA process flow notifies the completion of its execution via an email to the designated point of contact. A separate notification is sent containing the details in case of a failed execution. The email notification includes a note about the executions that take place during the off-season (Oct-May) or periods of local fishing restrictions. A sample screenshot of email notification is shown in Plate. 2.



HiFA INCOIS - Processing Date: 13-Jun-2024

HiFA INCOIS<[redacted]>
To: Alakes Samanta
Fri 12/13/2024 1:00 PM

Hi,
This is to inform you that HiFA_Latest_File_BanPeriod.nc has been generated in /home/users/hilsa/Op_HILSA/Output/2024/20240613/Prediction.

** Routine Run - Present date is in LOCAL FISHING BAN Period.

Cheers..

Hilsa Fishery Advisory (HiFA),
INCOIS

HiFA INCOIS - Processing Date: 29-Jun-2024

HiFA INCOIS<[redacted]>
To: Alakes Samanta
Fri 12/13/2024 5:09 PM

Hi,
This is to inform you that HiFA_Latest_File.nc has been generated in /home/users/hilsa/Op_HILSA/Output/2024/20240629/Prediction.

The file is ready for quality check and subsequent dissemination.

!! ALERT !! Present date falls INSIDE the ADVISORY DISSEMINATION Period.

Cheers..

Hilsa Fishery Advisory (HiFA),
INCOIS

Plate. 2 Screenshot of the HiFA notification email

6. Inauguration of the service

HiFA was launched on the 26th foundation day (3rd February) of INCOIS by the Director General, CSIR. (Plate. 3)

Plate. 3 Launching of HiFA by DG, CSIR in the presence of distinguished dignitaries.

7. Future scope

As described earlier, the prediction model was developed based on a smaller volume of geo-tagged Hilsa catch dataset. With the availability of more geo-referenced catch data, there is significant scope to further refine and enhance the accuracy of the existing prediction model. Improved data availability will help in capturing regional variations and trends more effectively, especially in the climate change scenario, leading to better prediction. Furthermore, the availability of a large data set will help to test other types of data intensive AI/ML models, which may provide better prediction accuracy. Additionally, there is a scope to develop dedicated regional prediction models for other key Hilsa fishing zones along the Indian coast, such as the Odisha and Andhra Pradesh coasts.

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