“Site Suitability Modelling of Asian Sea Bass (*Lates calcarifer*) on Bakkahli and Naf River Estuary Using Generalized Additive Model (GAM)”.

Course Title: Research Project
OCG-429

Submitted by
Reg. No: 2018136049
B.Sc Session: 2018-19

February, 2023

Department of Oceanography
School of Physical Science
Shahjalal University of Science and Technology,

"Site Suitability Modelling of Asian Sea Bass (*Lates calcarifer*) on Bakkhali and Naf river Estuary Using Generalized additive model (GAM)."

B.Sc. (Honors) Project

A project report has been submitted to the Department of Oceanography at Shahjalal University of Science and Technology, Sylhet, as a partial fulfillment of the requirements for the Bachelor of Science degree.

Submitted by,

Reg.no: 2018136049

Course code: OCG 429

Reg.no: 2018136049

Session: 2018-2019

Department of Oceanography

Shahjalal University of Science and Technology, Sylhet.

Submitted to,

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Candidates Declaration

I affirm that the project report titled **"Site Suitability Modelling of Asian Sea Bass (*Lates calcarifer*) on Bakkhali and Naf River Estuary Using Generalized Additive Model (GAM)"** is a representation of my own original work. Furthermore, I confirm that no portion of this report has been previously submitted for the purpose of obtaining any academic qualification.

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CERTIFICATE

Md.Nazmus Sakib, with registration number 2018136049, he conducted an original research work titled "Site Suitability Modelling of Asian Sea Bass (Lates calcarifer) on Bakkhali and Naf river estuary by Generalized additive model (GAM)." This research was carried out during the 8th semester of the BSc program in the Department of Oceanography at Shahjalal University of Science and Technology, Sylhet. This certification confirms the authenticity and originality of the thesis. This research study has been conducted under our guidance to fulfill the partial requirements for the BSc (Research Project) Degree in Oceanography at Shahjalal University of Science and Technology, Sylhet, Bangladesh.

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Acknowledgements

The support and encouragement of numerous individuals played a crucial role in the successful completion of this thesis. I am immensely grateful to each and every one of them for their unwavering support and encouragement throughout this journey. I would like to express my deepest gratitude to my advisor MD Shajjadur Rahman, Assistant Professor at the Department of Oceanography, Shahjalal University of Science and Technology. Their invaluable guidance, support, and encouragement have played a crucial role in shaping my research. I am truly grateful for their expertise, patience, and understanding.

I am deeply grateful to the Department of Fisheries and the Greenhouse Fisheries Hatchery in Cox's Bazar for their invaluable assistance in the laboratory component of my thesis. Their abundant resources, expertise, and guidance were instrumental in the accomplishment of my research.

I am deeply grateful to my family, friends, and colleagues for their unwavering belief in me, as well as their emotional support and encouragement. Most importantly, I express my heartfelt thanks to Almighty Allah, the most Kind and Benevolent, for all the blessings bestowed upon me.

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Abstract:

The objective of the current study is to understand the suitable location for aquaculture of Asian sea bass in the Bakkhali and Naf River. We performed a Generalized Additive Model that incorporated presence and absence data, in-situ physical parameter collection, satellite data, and observation. Our data was obtained from observation, in-situ collection and Satellite observation. The habitat and distribution of the Asian sea bass are significantly influenced by the salinity, depth, and feeding behavior, as revealed by our study. According to our study, there is a wide range of fish larvae and zoo plankton in the Bakkhali and Naf river estuary which make this zone suitable for Asian sea bass habitat. Our model predicted a moderate concurrence with on-site measurements (Area under curve = 0.6519), indicating a habitat of Asian sea bass occurrence ranging from (20% - to 70%). Our Study will act as a valuable asset for Bangladesh's endeavors in enhancing economic activities related to ocean-based fisheries. Specifically, it will serve as a guide for initiating commercial fishing and aquaculture of the Asian sea bass. One major challenge in this study involves the availability of up-to-date data analysis, the monitoring of seasonal trends, the investigation of appropriate cage site management, and the comprehension of diseases and environmental hazards. The aim of this study is to assist in providing comprehensive data regarding appropriate sites for establishing fish farms, as well as the distribution and migration patterns of the Asian sea bass.

1. Introduction

There are 13 species belonging to 3 distinct genera within the Latidae family that can be found across the globe. Among these species, the Asian seabass *(Lates calcarifer)* is included (Mab et al., 2016). Asian sea bass, also known as barramundi, inhabits the Indo-West Pacific regions, spanning from the eastern side of the Persian Gulf to China and Taiwan. Its distribution extends further southward to include southern Papua New Guinea and northern Australia(Hanif MA, 2015). In Asia, it is commonly referred to as "barramundi," whereas in Bangladesh and India, it is known as "bhetki" or "coral"(Klaus Riede, 2004). In Bangladesh, Asian sea bass can be observed inhabiting the estuaries of various rivers. These rivers include the Naf River in Teknaf, the Bakkhali river in Cox's Bazar (MAB et al., 2016a), as well as Chakaria, Karnafully river in Chattagram, Feni River, Sandwip, Char kukrimukri (MM & N. D. Monwar, 2013), Char chapli, Galachipa, Urir Char, and Hatiya. Additionally, this fish species can also be found in Barisal, Patuakhali, and Khulna, specifically in the Rupsha and Shibsha rivers near Khulna, Bagerhat, and Satkhira(MM & N. D. Monwar, 2013). The Ganges delta, Naf, Bakkhali, Sangu, and Karnafully are well-known coastal water estuaries in Bangladesh for spawning, nurturing, and feeding of Asian sea bass (Chaklader et al., 2015). This particular fish possesses a cannibalistic nature and exhibits an extremely carnivorous appetite (Boonyaratpalin, 1997). The Asian Sea Bass predominantly feeds on a range of *teleostei* species, such as *Apocryptes*, *Jonieops*, *Otolithoides*, *Harpodon*, *Coilia*, *Polynemus*, *Pama*, *Therapon*, *Chanda*, and *Gobiioides*. During the juvenile phase of the Asian sea bass, the zooplankton species that are consumed include *Euglena*, *cladocerans* (such as *Daphnia)*, *copepods*, *pony fish* (*Leiognathus sp*), and mullets (*Mugil sp*).

Moreover, shrimp larvae and megalopa serve as significant food sources for the Asian sea bass at its juvenile stage.(Kamruzzaman et al., 2015). Various environmental factors and water quality parameters play a significant role in influencing the sexual maturation, growth, development of gonads, distribution, feeding habits, and population of Asian sea bass. These factors encompass temperature, salinity, water depth, abundance of zooplankton, tidal patterns, pH levels, dissolved oxygen (DO), and the presence of nutrients like nitrate-phosphate, ammonia, as well as the quality of soil(Venkatachalam et al., 2018a). Asian sea bass can inhabit a wide range of aquatic environments, including fresh, brackish, and marine waters with salinity levels ranging from 15–30 PPT to 10–15m (Haque et al., 2020). The optimal temperature range for the growth of Asian sea bass is between 26.79°-32°(Md. Amirul Islam et al., 2023a). But Asian Sea bass can tolerate temperature 16.79 °-33°C (Cheung et al., 2013). The environmental conditions encompass a spectrum of salinity levels ranging from 25.34 to 32 parts per thousand (PPT), dissolved oxygen levels varying from 4 to 9 parts per million (ppm), pH levels spanning from 7.5 to 8.5, turbidity levels below 10 ppm, and minimal concentrations of NH_3, specifically less than 0.3 ppm and 1 ppm correspondingly (Haque et al., 2020). It inhabits within a range of 40-60 nautical miles from the shoreline (MAB et al., 2016b). The tide during the transitional monsoon season (April to June) has a significant impact on the reproductive activity of Asian sea bass (Haque et al., 2021). The female, for example, typically possesses a greater weight, whereas the males display thicker scales in the vicinity of the cloaca (Mathew Grace, 2009). The Asian seabass is considered one of the most potential candidate species because of its high fecundity, captive breeding, fast growth rate, nutritious meat, and market demand (Md. Amirul Islam et al., 2023b).

The majority of Asian seabass are males weighing between 1.5-2.5 Kg. However, as they grow and reach a weight of 4-6 Kg, most of them undergo a transition and become females (Irmawati et al., 2020). The techniques for producing Barramundi fry were first developed in Thailand during the 1970s. These techniques were further improved and perfected by research institutes in the Philippines, Singapore, Hong Kong, and Australia (Konovalov et al., 2018). The asian sea bass is highly suitable for aquaculture in Bangladesh. Cultivating barramundi through polyculture in ponds and experimental cage culture has gained significant momentum in the cox's bazar region. Wild seabass fingerlings and fry are collected from the Sundarban region during the post-monsoon period ("Coastal Set Bagnet Fishery in the Payra River, Bangladesh and Its Impact on Fisheries and Biodiversity," 2015). Salinity levels in the rivers vary significantly at a considerable distance upstream from the Bay of Bengal coastline Make this Zone suitable for Asian sea bass culture (Fadlaoui et al., 2021). In 2009, the production of Asian sea bass amounted to 49,172 tonnes. This figure increased to 67,094 tonnes in 2010, followed by 68,949 tonnes in 2011. In 2012, the production further rose to 77,538 tonnes, and in 2013, it reached 75,370 tonnes (Haque et al., 2021). These quantities were achieved through a combination of aquaculture and artisanal fishing methods (Fadlaoui et al., 2021). To choose an appropriate cultural location, it is essential to take into account the composition of clay or sandy bottoms because it has ability of the soil to retain water and the absence of acid-sulfate, and pollution in soil (Md. Amirul Islam et al., 2023a) . Ideal conditions for seabass culture include a tidal fluctuation of 2-3 meters with the ability to admit and drain water during high and low tides (Jerry, 2013). Proper water circulation is crucial to guarantee the efficient elimination of different waste materials from the bass aquaculture location (Mohd Nor et al., 2019).

1.2 Objectives:

1. To identify the suitable site for aquaculture of the Asian sea bass.
2. To understand the distribution of this species along the coastal area of southeast coast of Bangladesh.
3. To assess the real environmental factors that impact the growth and distribution.

2. Literature Review

Scope and Purpose	Critical Evaluation	Analysis and Synthesis	Critical Discussion	Reference
Conserve and identify the suitable site for the Sea weed.	Used mainly GAM modelling by using different types of environmental variables.	Area under curve(AUC), Multicollinearity, Prediction and production.	Discuss about the suitable environmental parameter for the seaweed occurrence, And identify the suitable area in Bangladesh coast.	(Sarker et al., 2021)
Mainly identify the feeding behavior of Asian se bass by gut analysis.	Separate the zooplankton and juvenile fish species	Calculation of the monthly Fullness Index	Identify the feed has to provide during the aquaculture of Asian sea bass.	(Kamruzzaman et al., 2015)
Identify the environmental parameter	The survival and expansion of fish within an aquaculture system is of utmost importance.	The survival rate of Asian sea bass can be assessed by cultivating them in the mangrove area and monitoring the continuous water parameters.	Potential use of mangrove swamp for fish farming industry	(Venkatachalam et al., 2018)
For conduct mariculture in the vast coastal area of Bangladesh.	Using the observation of Asian sea bass culture in the patuakhali region of Bangladesh.	By culture techniques from different countries.	Describe about the Important environmental perameter for aquaculture of the Asian sea bass	(Chaklader et al., 2015; Guisan et al., 2002; Haque et al., 2021)
Habitat suitability modelling and niche theory, to understand how we can conduct the habitat modeling.	Discuss about several techniques and parameters that helps to estimate the modeling purpose		Ecological niche and fitness of habitat.	(Hirzel, 2008)
To understand Behavior, distribution, food availability, migration pattern.	Conduct artificial breeding.	Artificial breeding and Spawning	Discuss about the environmental parameter during the culture periods.	(Mohammed Ashraful Haque, 2019)

3.Materials and Methods

3.1 Study Area

The Bay of Bengal spans approximately 118,813 square kilometers and serves as a habitat for a diverse range of species across its three unique coastal areas: the southwest coast, central coast, and southeast coast. Bangladesh possesses a coastline that stretches for 710 kilometers, encompassing a vast expanse of approximately 47,201 square kilometers. This coastal region accounts for approximately 32% of the total land area of the country. The investigation took place in the estuary of Bakkhali and the Naf River, situated in the Cox's Bazar district of Bangladesh. This specific region in the southeastern part of Bangladesh is well-known for its vast muddy flats and sandy coastlines. This area is blessed with a multitude of remarkable rivers, such as Matamuhuri, Bakkhali, Naf River, Maheshkhali channel, and Kutubdia channel. These rivers play a crucial role in not only transporting sediments but also supplying essential nutrients, all while being greatly affected by tidal movements. The Asian sea bass aquaculture is facilitated by the provision of nutrients, abundance of zooplankton and fish larvae, the influence of tides, moderate salinity, and protection against the impact of high waves. These factors collectively create an ideal environment for cultivating Asian sea bass in this particular zone (Glenn Schipp, 2007).

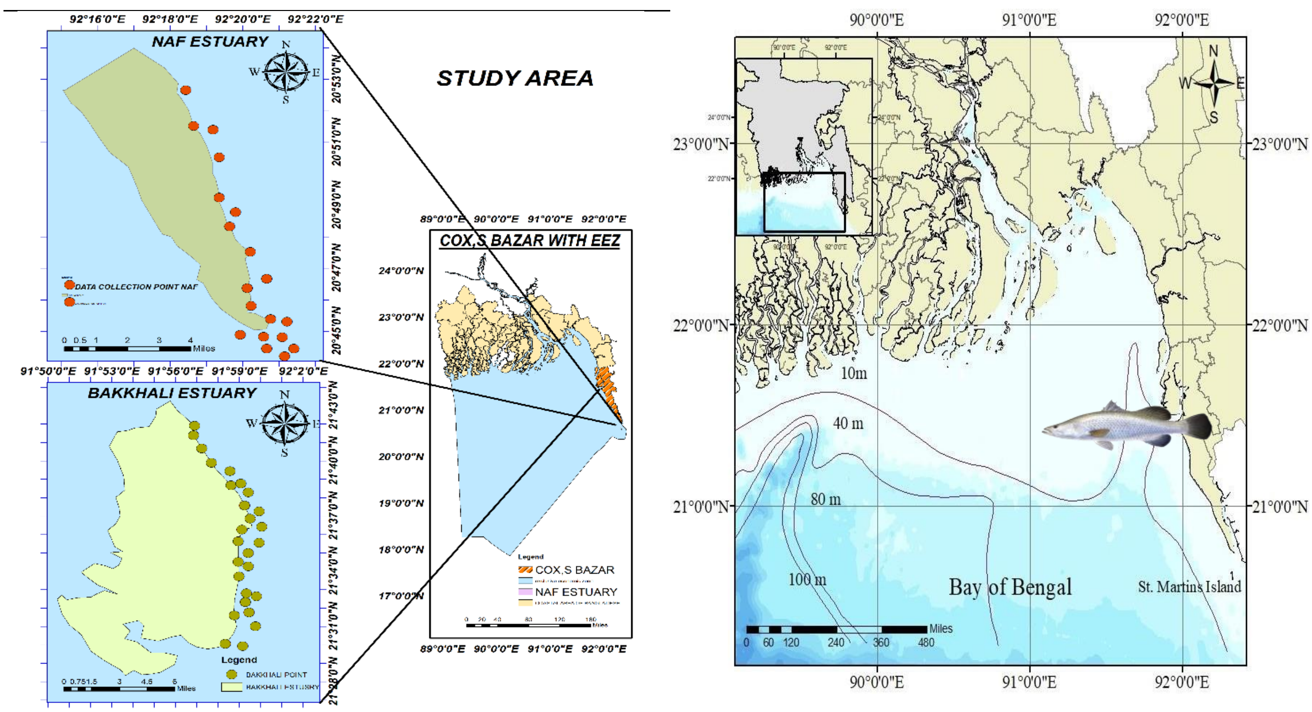


Figure 1 : The geographical location of the study area is defined by the data points found in the estuaries of the Bakkhali and Naf rivers. These data points represent the collection points for the study area's data.

3.2 Data Collection

The dependent variable for Site Suitability modeling in this study was the presence and absence of Asian sea bass, based on the data utilized. The variables taken into account for explanation were the temperature of the sea surface (SST), salinity, DO (Dissolved Oxygen) the concentration of NO_3, photosynthetically active radiation (PAR), the water current in both the zonal and meridional directions, and the total suspended matter (TSM) in addition to depth and chlorophyll concentration. The selection of explanatory variables was determined through a comprehensive review of relevant literature(Jerry, 2013), (MM & N. D. Monwar, 2013), (Venkatachalam et al., 2018b), (MAB et al., 2016b), (AftabUddin et al., 2021), (Williams et al., 2003). The levels of NO3, abundance of zooplankton and fish larvae, and tidal influence commonly exert an influence on the growth, distribution, and maturity of the Asian sea bass (Hajirezaee et al., 2015). The data used for this study were obtained from on-site observations, satellites, simulations conducted by models, and Article based sources. Data were collected from the estuary of the Bakkhali and Naf rivers, both upstream and downstream. The information regarding the collection of data is provided in the *(Table-01)*. Data was collected from August 2023 to November 2023, an extensive series of field surveys were carried out across a grand total of 11 distinct locations. During this time frame, we ensured to collect samples from every site on a monthly basis. Among the 11 locations, 2 were dedicated to hatcheries, while an extra 2 were designated as experimental sites for cage culture farming. The asian sea bass aquaculture sites are located in Moheshkhali and Khuruskul.

1.Presence and Absence:

During our discussions with the fishermen, we observed the existence of Asian sea bass at a particular sampling site, whereas it was considered to be absent in other areas. Data pertaining to the presence and absence of Asian seabass was gathered through field surveys and acquired from the hatchery located in the Cox's Bazar region. Furthermore, the current study employed a dataset obtained from fisheries Ghat Coxs Bazar, encompassing extensive information on the presence and absence of Asian sea bass. We have collected on-site data pertaining to the present and absent of Asian sea bass based on the analysis conducted in the review paper (Mushahida-Al-Noor et al., 2013), (AftabUddin et al., 2021; Hajirezaee et al., 2015; Haque et al., 2021; MAB et al., 2016b; Md. Amirul Islam et al., 2023c).

2. In-Situ Data:

Data were collected in-situ from 11 different locations, namely Khurushkul, Moheshkhali, Nuniarchara, Matamuhuri, Shamlapur, Teknaf, and Shah Porir Dip Terminal. The collection process involved the use of CTD (Conductivity, Temperature, and Depth) instruments and Algal torch equipment *(Fig-02)*.

3. Satellite Data Collection:

Satellite data was acquired from the NOAA website, specifically from the (www.oceancolor.gsfc.nasa.gov), as well as from the Aqua Modis satellite, with a resolution of 4 Km. Data on depth were gathered from the freely accessible satellite platform (*GEBCO - The General Bathymetric Chart of the Oceans*, n.d.). And the salinity data is derived from the (*Home*

| *OPeNDAP™*, n.d.) site. The nitrate data of the coastal zone of Bangladesh is gathered from the open source platform www.resourcewatch.org.com.

4.Zooplankton Data collection:

Water sampling is conducted at every designated site to determine the prevalence of fish larvae, shrimp larvae, and megalopa, which serve as crucial indicators of the Asian sea bass's primary food sources (Kamruzzaman et al., 2015). In August and November, a two-month sample was collected using the zooplankton net from 8 station. The collection of Zoo-Plankton sample involved the filtration of approximately 30-36 liters of river water, followed by the storage of the filtered water in a bottle (Mack, Heidi R et al., 2015). The station name was used to label the filtered water, which was then transported to the laboratory for identification and analysis. The samples were stored in a 5% formalin solution to facilitate the qualitative and quantitative analyses as well as zooplankton species identification (Goetze Erica et al., 2013). The sample were kept in the fridge at a temperature of -4 °C until they were ready for further examination (Mack, Heidi R et al., 2015).

Table 1 : Details of data used for Asian sea bass suitability modeling in this study.

Variable	Unit	Abbreviation	Source	Reference
Presence and absence	Binary data (1=presence, 0 =absence)		In-situ and Observation	(Hanif MA, 2015) (Habib, Islam, & Mohsinuzzaman and Rahman, 1984) (Hossain MA, 1997)
Sea surface temperature	◦ C	SST	Satellite/Insitu	www.oceancolor.gsfc.nasa.gov www.noaa/avhrr.pathfinder
Total suspended matter	g/m3	TSM	Satellite	Aqa-modis, Aqua-terra
Photosynthetically active radiation	W/m2	PAR	Satellite	www.oceancolor.gsfc.nasa.gov
Surface eastward geostrophic sea water velocity	m/s	U current	Satellite	www.aviso.altimetry.fr
Meridional geostrophic velocity current	m/s	V current	Satellite	www.aviso.altimetry.fr
NO3 concentration	µmol/l		Secondary Data	(Vizzuality, n.d.) www.resourcewatch.org.com.
Depth	m		Satellite	www.gebco.net
Chlorophyll	µmol/1	Chlo	Satellite	www.oceancolor.gsfc.nasa.gov
Salinity	PPT		In-situ/Satellite	(*Home* | *OPeNDAP™*, n.d.)

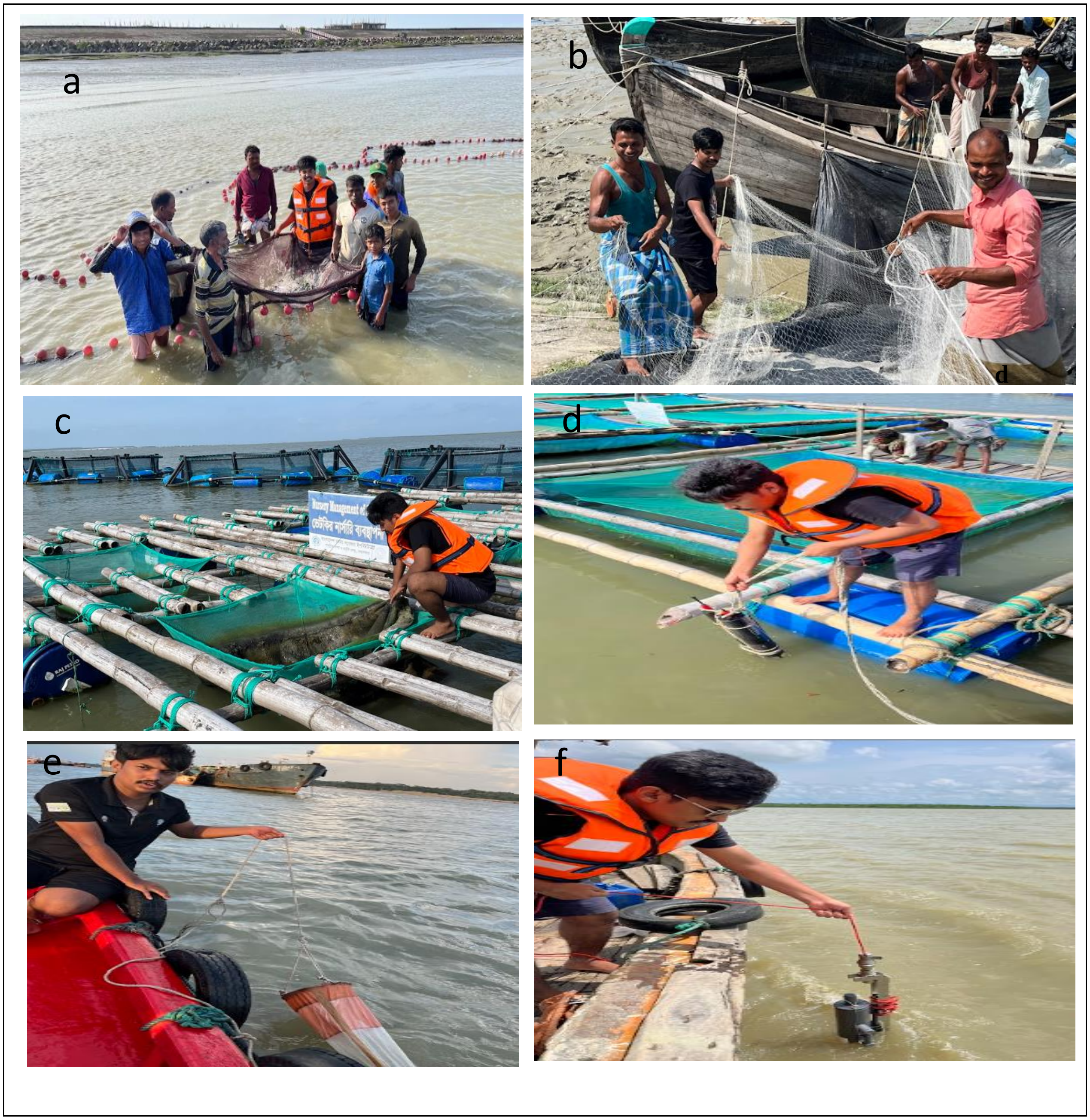


Figure 2 : Ongoing aquaculture initiatives for Asian sea bass in the coastal region of cox,bazar (a) discussion with the fisherman regarding the existence in the Bakkhali river , (b) A discussion with the fisherman regarding the existence and nonexistence in Naf river,(c) juvenile culture of asian sea bass, (d,e) Water sample collection, (f) the collection of physical parameters is conducted using CTD and Algal torch.

3.3 Data Processing:

3.3.1. Satellite Data processing:

The Snap software is utilized to input the NC file obtained from the sentinel-3 satellite, followed by the application of a mask on the identified area using the coordinate system. Subsequently, the files are transferred to the ArcGis software, where random points within the masked area are selected to extract the Average data. The interpolation method of ArcGIS's Spatial analytic tools is utilized to convert the data points into a raster layer. Similar to the previous approach, we obtained the Depth data from the website *www.gebco.net* and applied a masking technique to identify specific areas based on the coordinate system. Subsequently, we utilized random points to extract the collected data and converted it into a raster layer.

3.3.2. In-situ data processing:

1.Present and absence: The geospatial data set, also known as a point shape file, was created by merging presence and absence data from various sources into a single data set (Sarker et al., 2021).

2.Salinity: We measure the conductivity of the Water by Using the CTD (conductivity, temperature, Depth). The temperature and conductivity are related to each another, so it may be necessary to account for temperature variations. calculate salinity using the Practical Salinity Scale (PSS-78) formula (Lewis & Perkin, 1981):

$$S=0.0080\times C_{25}^{1.726}$$

Here, C_{25} is the compensated conductivity, C_t is the measured conductivity at temperature T.

S is the salinity in Practical Salinity Units (PSU).

Than we convert the (PSU) salinity unit to the (PPT) salinity Unit by using the simple formula:

$$\text{Salinity (ppt)}= \text{Practical Salinity (PSU)}/1.0046.$$

3.Surface Temperature:

The temperature data is gathered from the sample point through the utilization of the CTD device. Subsequently, the Average temperature of these points is determined using Microsoft Excel. The temperature values are then converted into a CSV file format and further processed through interpolation to create a raster layer.

4.Zooplankton analysis:

Various instruments and implements, including microscopes, slides, and identification guides, are utilized in the process of laboratory analysis. The zooplankton was concentrated by filtering the preserved water sample. Subsequently, the sample was transferred onto a slide. A microscope is utilized for the identification and enumeration of various species of zooplankton.

3.4 Modelling Framework

The distribution of Asian sea bass in the Naf and Bakkhali river estuary was defined by employing the Generalized Additive Model (GAM) through a presence and absence approach, which allowed us to identify the environmental variables that best describe this distribution *(Fig-03)*. The Generalized Additive Model (GAM) was created by Hastie and Tibshirani with the purpose of establishing a connection between a single response variable and several predictor variables(Hastie & Tibshirani, 1986). The GAM model represents a nonparametric regression model (V. Lauria, 2015). GAMs utilize smooth functions as predictors, providing them with enhanced flexibility compared to linear regression models (Simpson, 2018). GAM is employed to uncover and assess the non-linear impacts of the predictor variable on the dependent variable. The combination of basis functions allows GAM to represent a vast array of functional relationships. GAM is extensively utilized in species habitat modeling. GAM is characterized by its smooth function nature. GAM is extensively utilized in species habitat modeling. Antoine Guisan and Trevor Hastie, for instance, employed a method to forecast the distribution and abundance of species (Guisan et al., 2002). GAM is frequently employed to determine the appropriate location for the species and its preservation. GAM was utilized by Subrata Sarker to determine the appropriate habitat for the sea weed (Sarker et al., 2021). We conducted an analysis of Variance Inflation Factor (VIF) to assess the multi-collinearity of explanatory variables. The reason behind conducting a multi-collinearity test was due to the intricate characteristics of ecological data, which can impede the effectiveness of a regression model(Graham, 2003). After conducting a multi-collinearity test, the GAM technique was utilized to analyze the data pertaining to the presence or absence of Asian sea bass, along with the chosen explanatory variables The gam model determines the presence or absence of Asian sea bass at a specific location and time, as well as the value of the explanatory variable at that location.The GAM model is:

$$(N_{i,t} = \alpha + \sum n_j = 1\ f_j\ X_{j,i,t}) + \epsilon \ (eq{:}01)$$

Here, $X_{j,\,i,\,t}$ = Presence or Absence, I = Location, T = Time. j^{th} = value of explanatory variable, F_j = smoothing function for explanatory variable, ϵ = unexplained variation.

The GAM smoothing predictors were chosen using the MGCV library in the R statistical software. The selection of the smoothing degree is determined by the restricted maximum likelihood (REML) estimation method (Sarker et al., 2021). We used a binomial error distribution for the purpose of GAM fitting (Graham, 2003; Sarker et al., 2021). We employed the Akaike Information Criterion, which recommends choosing a model with the smallest AIC penalty. We selected the optimal model that incurred the lowest AIC penalty. The asian sea bass probability estimation was obtained by applying the final GAM in predictive mode to a comprehensive range of values for explanatory variables. The extracted data was split into two separate data sets. Two-thirds of the data were utilized for model fitting, referred to as the training data set, while the remaining one-third was allocated for model validation, known as the testing data set (Sarker et al., 2021). The receiver operating characteristic (ROC) curve was utilized, and the area under the receiver operating characteristic curve (AUC) was estimated. A model with an AUC value greater than 0.9 demonstrates excellent performance, while values between 0.7 and 0.9 indicate very good performance. An AUC value of 0.5 suggests that the model's performance is no better than that of a random model (Elith et al., 2006).

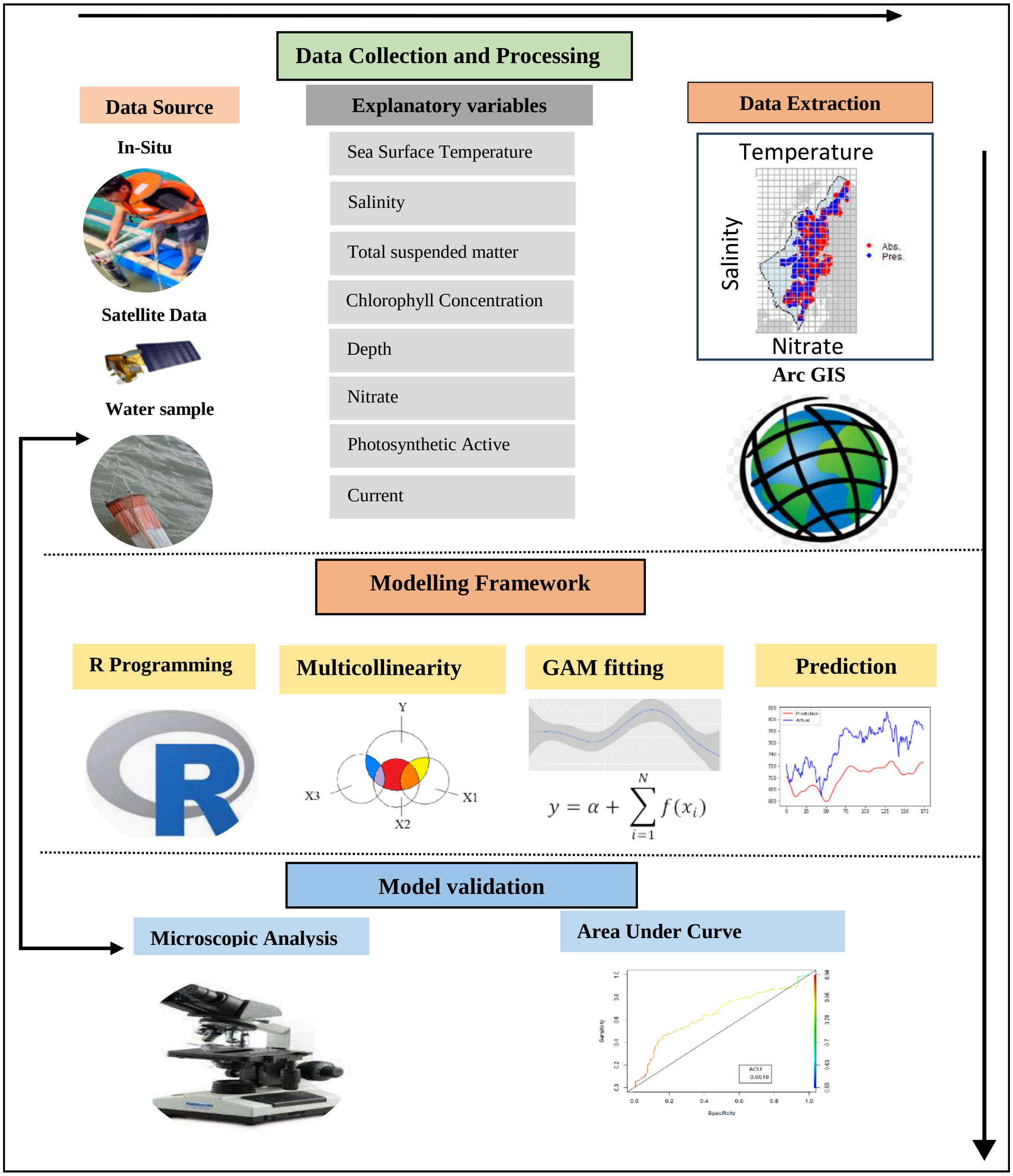


Figure 3 : A schematic representation of the site suitability model for the Asian sea bass which involves extracting data on environmental parameters from raster datasets of each variable at the locations where Asian sea bass are found. These extracted data are then utilized for fitting a Generalized Additive Model (GAM), while the raster dataset of environmental datasets is employed for spatially predicting the occurrence of Asian sea bass

4. Result:

A correlation analysis was conducted to understand the existence of multi-collinearity among the 8 explanatory variables investigated in this study, which include SST, Salinity, NO_3, PAR, u current, v current, TSM, Chlorophyll and depth. Using a set of 8 explanatory variables, we constructed generalized additive models (GAM) to analyze the data. Our analysis suggests that there is no significant correlation observed between these variables. There is no discernible correlation among these variables, as our findings indicate. The contributions of these 8 explanatory variables were taken into account in order to estimate their impact on the site suitability model *(Fig-04)*.

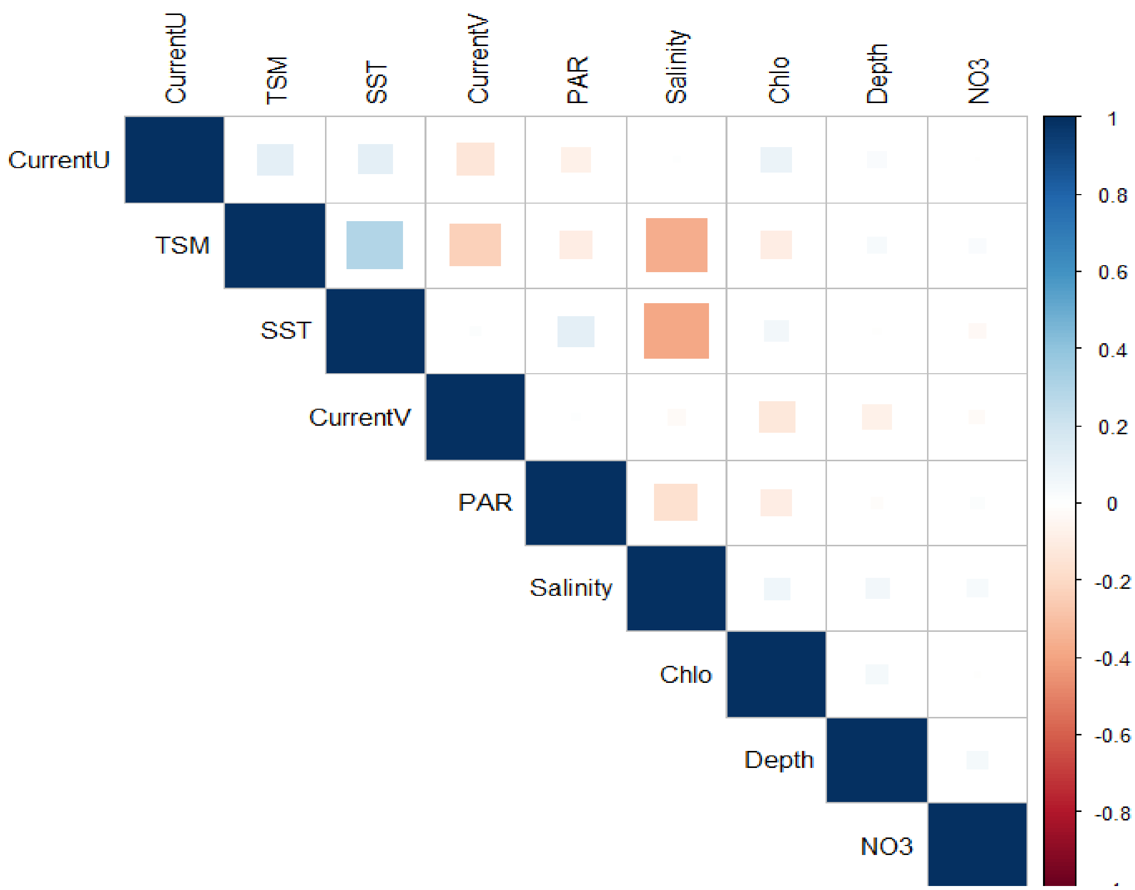


Figure 4 : The Pearson correlation matrix displays the association between explanatory variables. The correlation values range from 1 to +1. A value of -1 indicates a strong negative correlation, while a value of +1 indicates a strong positive correlation. A value of 0 indicates no correlation. Nitrate is represented by the chemical formula NO_3, while TSM= Total Suspended Matter, PAR= Photosysthetically Active Radiation, SST= Sea Surface Temperature, Chlo = Chlorophyll. Nitrate is represented by the chemical formula NO3, while TSM= Total Suspended Matter, PAR= Photosysthetically Active Radiation, SST= Sea Surface Temperature, Chlo = Chlorophyll.

During the study period, the anticipated map *(Figure-05)* revealed that the coastal waters were predominantly occupied by suitable sites for Asian sea bass occurrence and distributions. The Bakkhali river estuary, Bakkhali channel, Tin Nodir Mohona, Moheshkhali, Mathamuhuri, and Naf Estuary coastal zone of Bangladesh were identified as areas with a higher Probability of Asian sea bass distribution. It is worth noting that we observed a notable absence of suitable habitat for Asian sea bass in the upstream region.

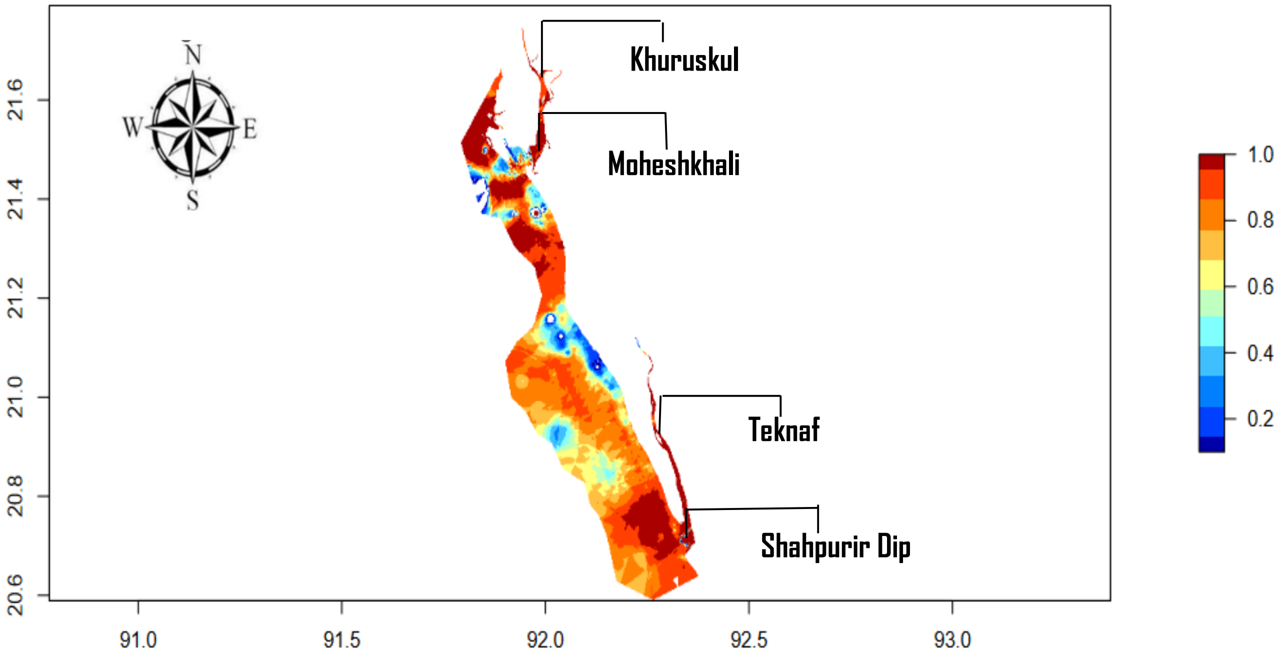


Figure 5 : The coastal area of Bangladesh has been analyzed using a Generalized Additive Model (GAM) to predict the occurrence probability of Asian sea bass. The distribution of this probability has been mapped, with a probability of 1 indicating a 100% occurrence probability of Asian sea bass in the region.

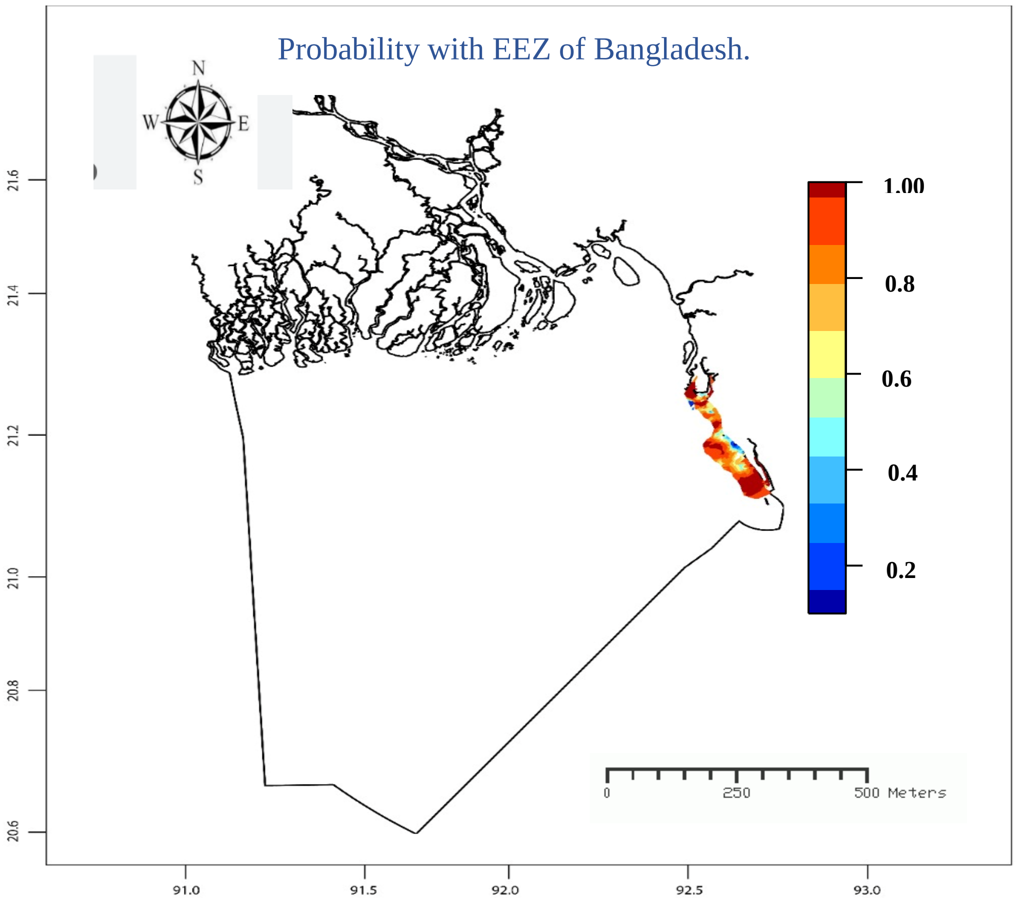


Figure 6 : Spatial distribution of Asian sea bass Site probability predicted by Generalized Additive Model (GAM) in the South east coastal area of Bangladesh with EEZ (Exclusive Economic Zone).

In the southeastern coast of Bangladesh, particularly in the Cox's Bazar region, we discovered that an approximate area of 420 km^2 exhibited a site suitability range of 50-100% for Asian sea bass*(Fig-05)*. The study findings indicated that approximately 275 km^2 of the area displayed a higher habitat (75%–100%) of being a suitable site for the species. Conversely, the remaining area exhibited a comparatively lower probability (20 - <50%) of being suitable*(Fig-07)*.The Moheshkhali channel, khuruskul channel, tin nodir mohona, Matamuhuri channel, naf river channel, and shahpuri beach area are the regions where the habitat of Asian sea bass occurrence is higher*(Fig-06)*.

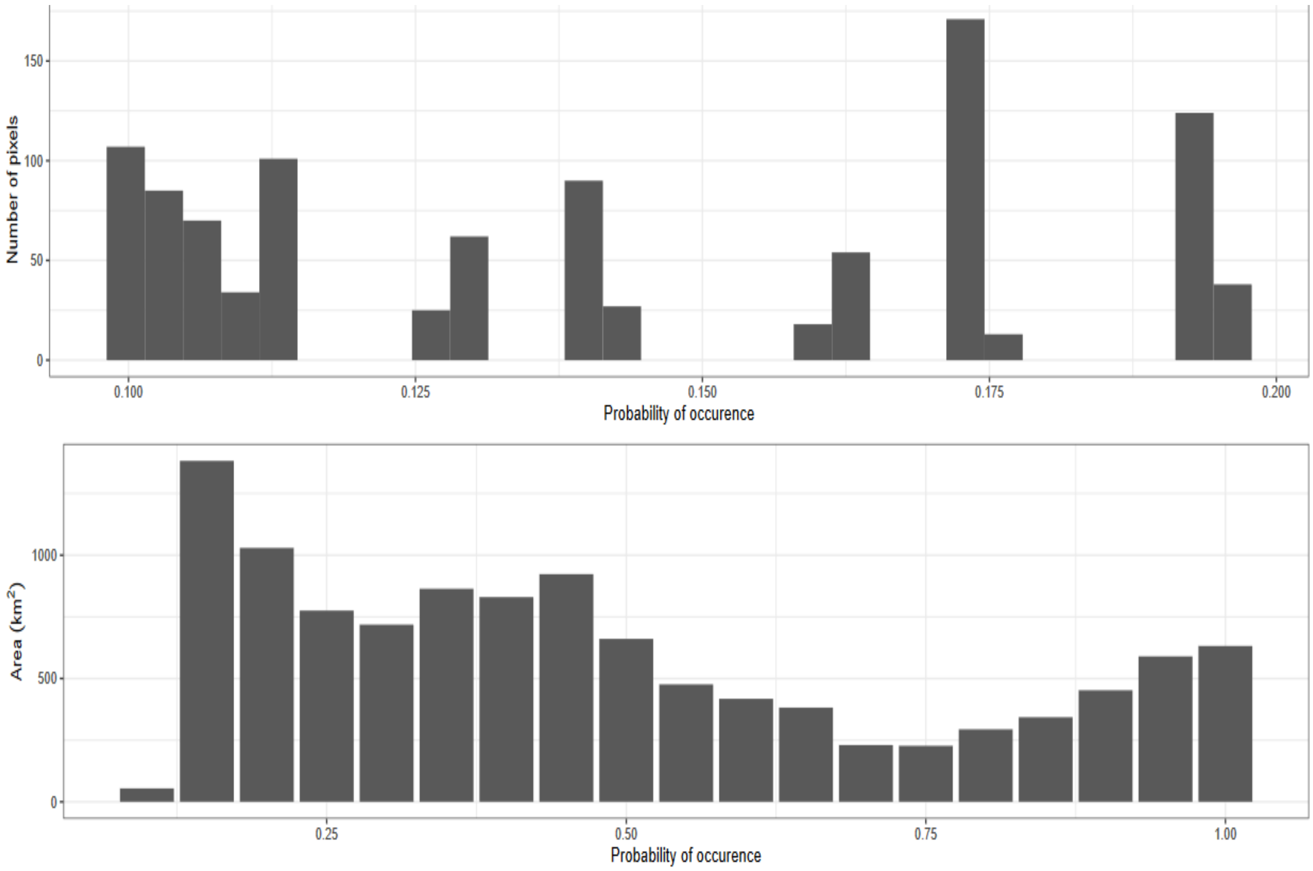


Figure 7 : The probability class of Asian sea bass occurrence in the southeast coast of Bangladesh determines the suitable site area.

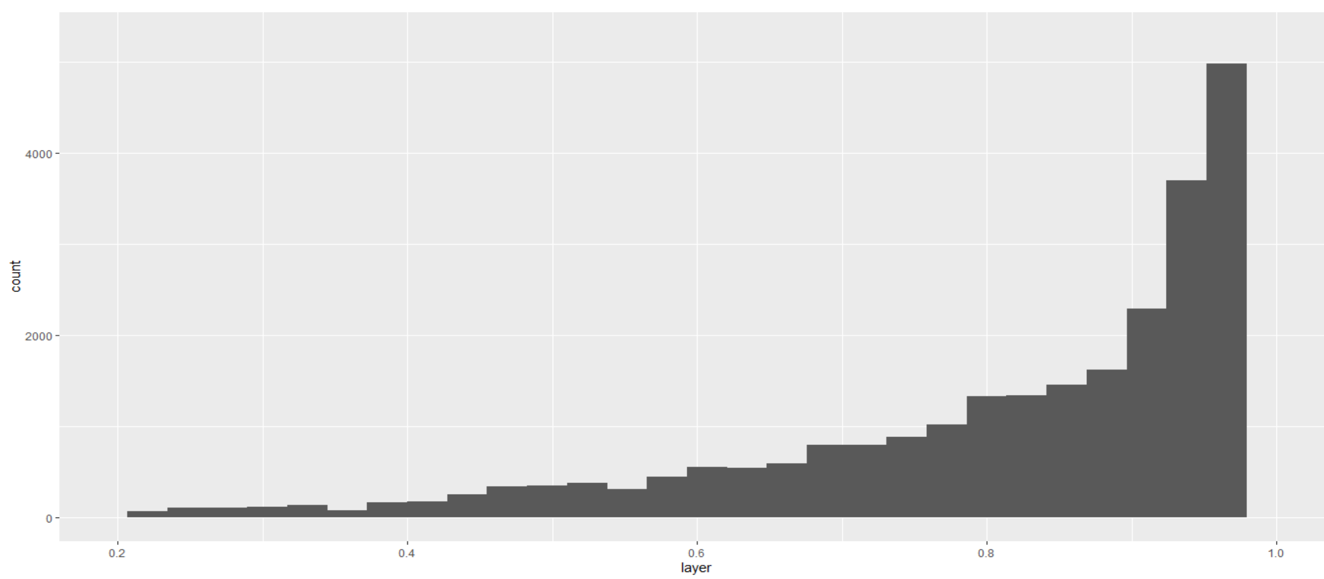


Figure 8 : Layers of occurrences of suitable site identification for the Asian sea Bass.

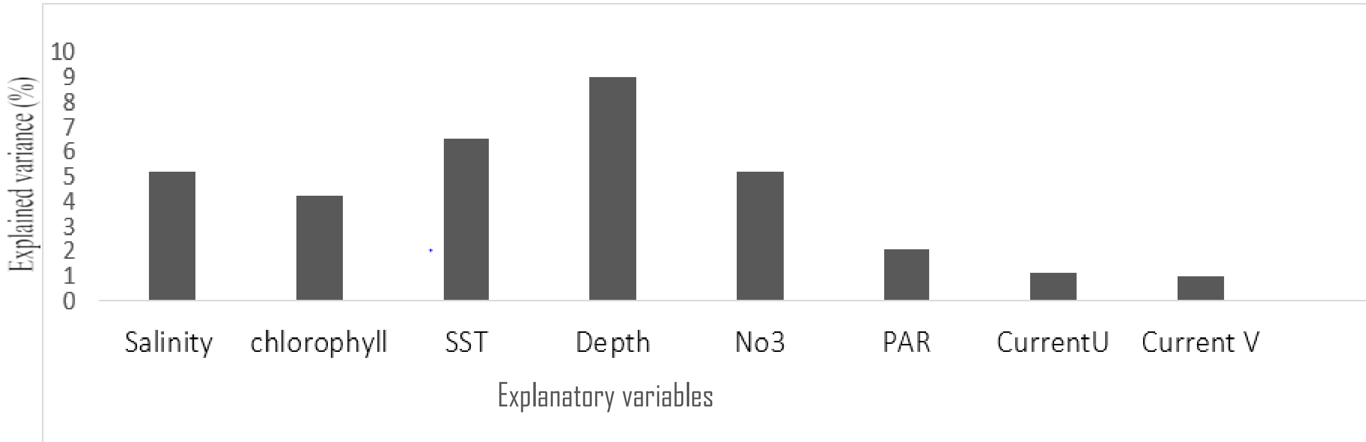
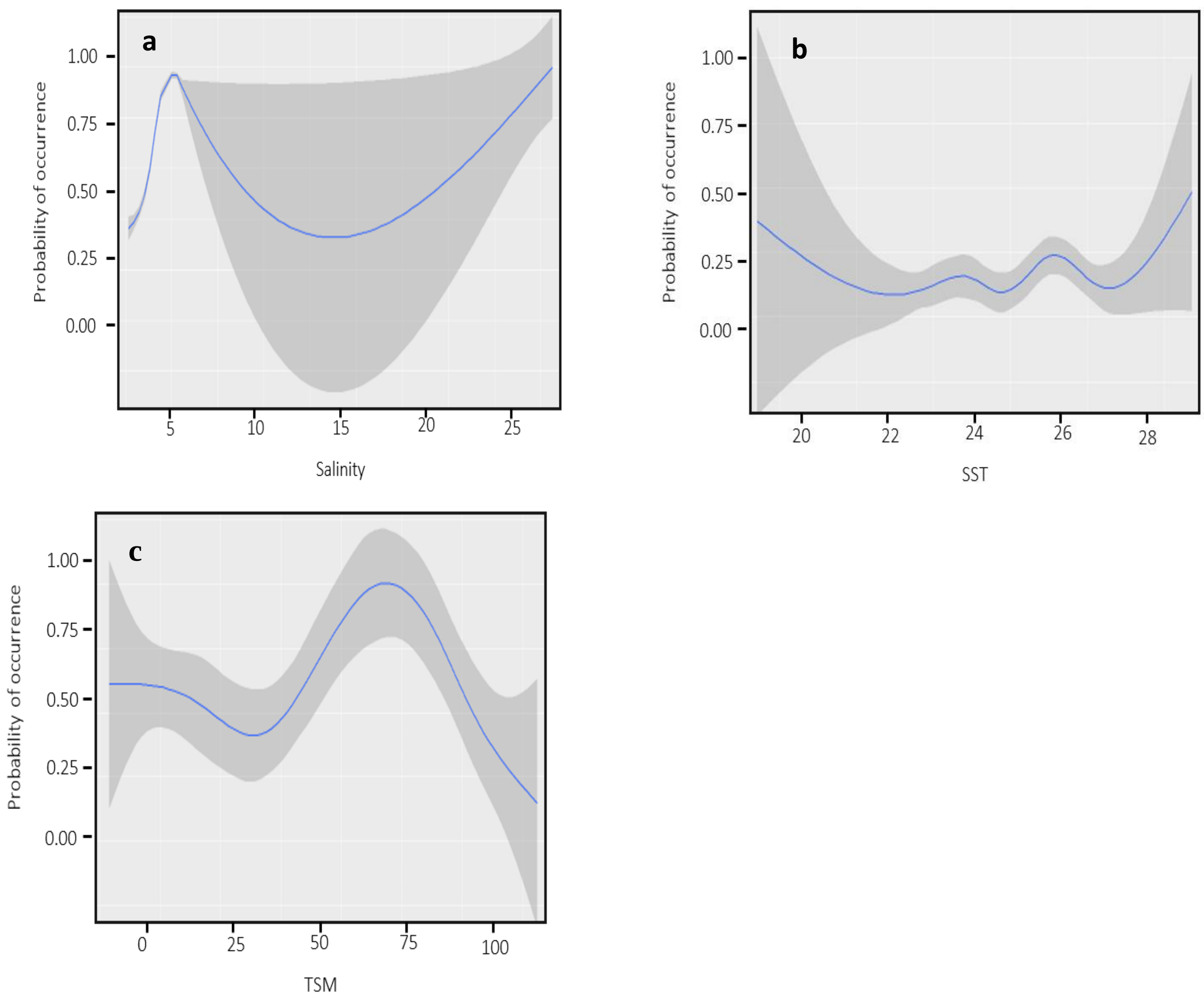


Figure 9 : The explanatory power of the individual variables employed in the Generalized Additive Model (GAM) for identifying a suitable site for Asian sea bass is significant.

The most significant factors were found to be depth, with a high explanatory power of 9% ($p < 0.01$), and salinity, which closely followed with 5.5% ($p < 0.01$). Other factors that were determined to be significant included NO_3 concentration (3.5%, $p < 0.01$), SST, chlorophyll (6%, $p < 0.01$), u current (1.1%, $p < 0.01$), and v current (0.9%, $p < 0.01$) *(fig-09)*.



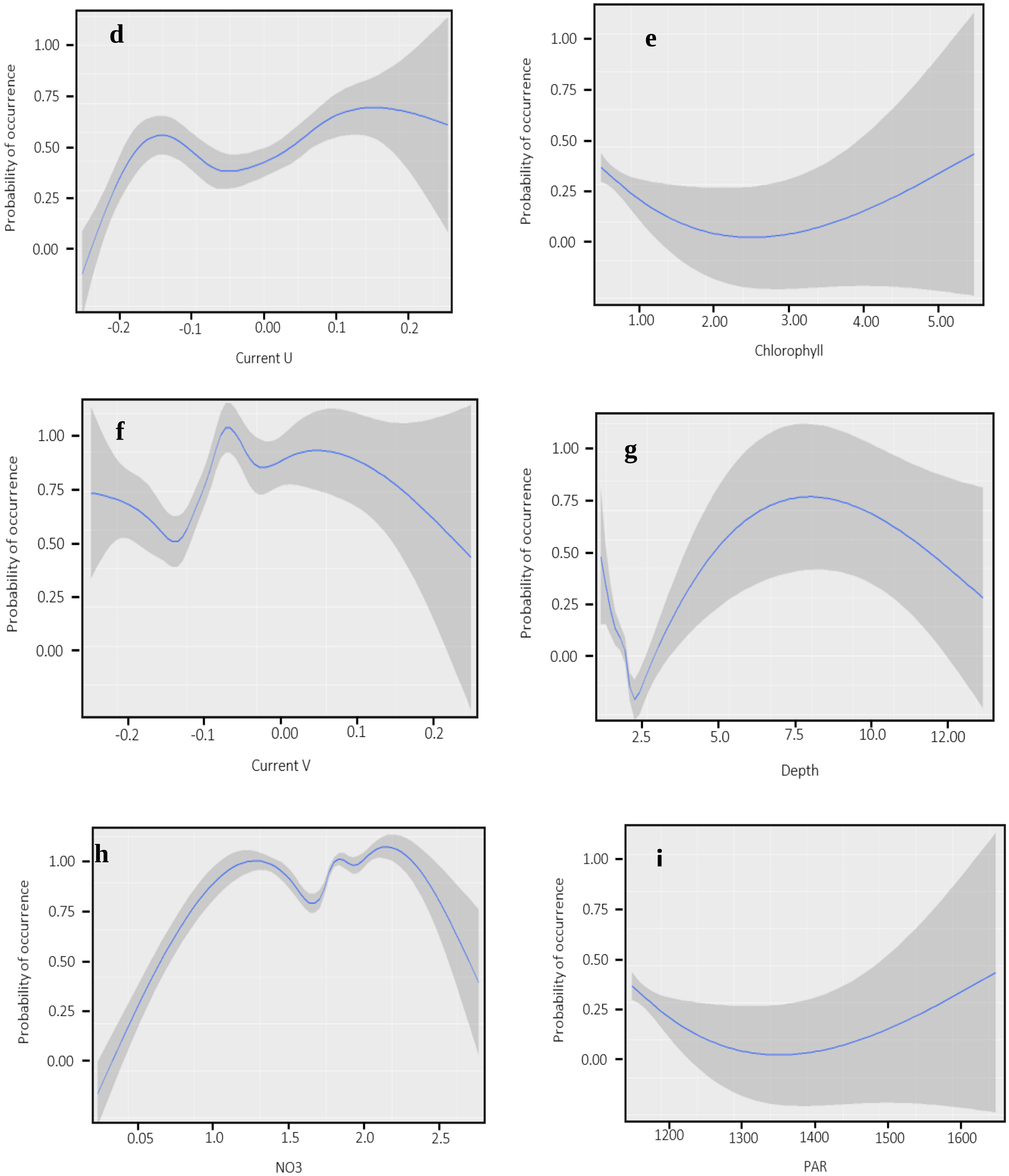


Figure 10 : Generalized Additive Model (GAM) was used to assess the suitable sites for Asian sea bass along the southeast coast of Bangladesh under various environmental conditions. (a) Salinity, (b) (a) Sea Surface Temperature (SST) (◦C) Total Suspended Matter (TSM), (d) surface eastward geostrophic sea water velocity in ms $^{-1}$ (u current), (e) chlorophyll, (f) the meridional component of the absolute geostrophic velocity current in ms^{-1}, (g)depth, (h) nitrate (µmol/L),(i) photosynthetic Active radiation.

(Fig-10) illustrates the depicted correlation between the suitability of Asian sea bass habitats and the factors that influence them. The results of our model indicate that the most favorable location has a higher chance of being found in the range of TSM values between (25 - 50), combined with a moderate level of salinity (5 -15). Additionally, higher nutrient levels (with NO3 concentrations of 1.6 to 2 μmol/l), shallow water depths between (7.5 and 10 m), and moderate current speeds (ranging from -0.01 to 0.1 m/s for both u and v currents) are also factors to consider. Furthermore, the ideal sea surface temperature (SST) falls within the range of 24 to 28 ◦C. Chlorophyll levels serve as a significant gauge of food availability for Asian sea bass. Our research revealed that the concentration of chlorophyll fluctuates within the range of (4-5).

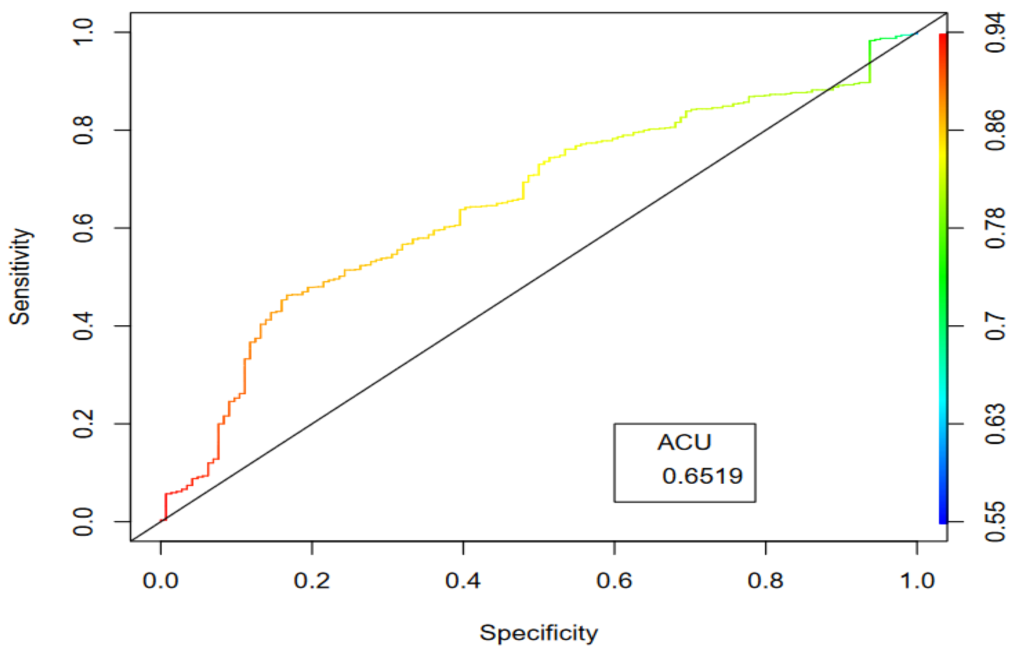


Figure 11:Estimations of the receiver operating characteristic (ROC) are derived from data concerning the presence and absence of Asian sea bass, as well as the predicted probability of their occurrence.

The AUC value indicates that, in approximately 65% of instances, a random selection from the positive group will yield a higher score than a random selection from the negative group.

According to Md. Kamruzzaman's analysis of the diet of Asian sea bass, zooplankton (19.91%), insects (9.02%), algae (7.69%), and macro-crustaceans (26.32%) make up a substantial portion of the fish's diet. During his Study, he came across various aquatic zooplankton such as *Euglena*, *cladocerans (similar to Daphnia), copepodes (resembling Calanoides),* pony fish (like *Leiognatus sp.),* mullets (such as *Mugil sp*.), *shrimp larvae*, and *megalopa* (Kamruzzaman, 2013).

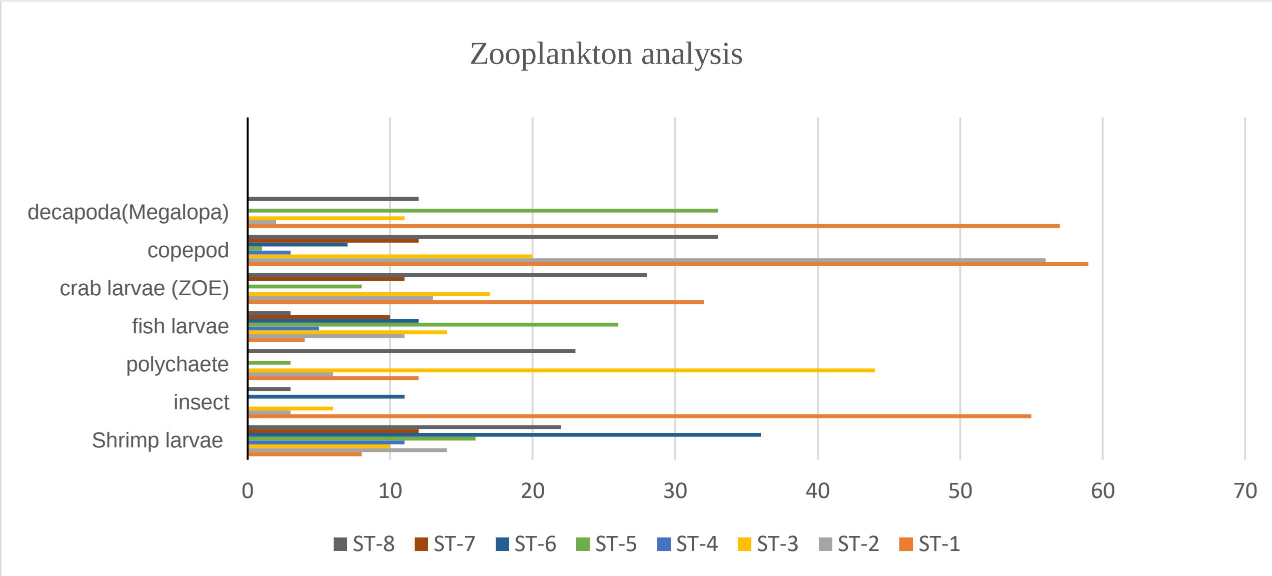


Figure 12 : Analysis of zooplankton was conducted at seven different stations in the Cox's Bazar region.

In this region, an abundance of food for the Asian sea bass is provided by a diverse range of zooplankton species. These include the *megalopa*, *copepod*, *crab larvae (ZOE)*, *fish larvae*, *insect*, and shrimp larvae (*Fig12)*. During our analysis of zooplankton, we discovered various categories of macrozooplankton. The Tin noder mohona at station 1 exhibited the highest concentration of zooplankton, particularly crab larvae *(zoe)* , *insct*, and *fish larvae*.

5. Discussion:

The study identified several coastal areas, including Bakkhali river estuary, Tin Nodir Mohona, Moheshkhali, Mathamuhuri, and Naf Estuary, as having a higher probability of Asian sea bass distribution. In the Cox's Bazar region, an area of approximately 420 km^2 exhibited a site suitability range of 50-100% for Asian sea bass. In the Cox's Bazar region, an area of approximately 420 km^2 exhibited a site suitability range of 50-100% for Asian sea bass. Notable absence of suitable habitat was observed in the upstream region.

According to our model's estimation, the primary factor influencing the distribution of Asian sea bass in the southeast coastal zone, particularly in Bakkhali and Naf River estuary, is the combination of salinity and depth. Depth and salinity were identified as the most significant factors influencing habitat suitability because the growth, migration, sexual maturation, and spawning activities of Asian sea bass are highly dependent on specific salinity ranges and depth levels (Elith et al., 2006). Other significant factors included NO3 concentration, SST, chlorophyll, u current, and v current (MM & N. D. Monwar, 2013). Reference to (Md. Kamruzzaman's.,2013) analysis of Asian sea bass diet revealed zooplankton, insects, algae, and macro-crustaceans as substantial components. Various aquatic zooplankton species, including Euglena, cladocerans, copepods, pony fish, mullets, shrimp larvae, and megalopa, were identified as part of the fish's diet.

In the South east coastal area, particularly in Bakkhali and the Naf River estuary, our study also identified Moderate levels of salinity and various depths. After analysis, it has been determined that the primary factor to consider when choosing a suitable location for the Asian sea bass is the temperature of the ocean's surface (Williams et al., 2003). The Asian Sea bass is well-known for its exceptional ability to adapt to different sea surface temperature(Venkatachalam et al., 2018b; Williams et al., 2003). Our model's Predict corroborates this fact, suggesting that the optimal growth conditions for the sea bass occur within the temperature range of 26° to 28°. The role of SST in the growth of Asian sea bass is considered complimentary, but it also acts as a limiting factor (Shoukang M, 2018).

This is because high temperatures can increase the pH of the water, which in turn affects the life cycle of the Asian sea bass (Shuangyao W, Zhiqiang J, & Shoukang M, 2018). According to (Venkatachalam et al., 2018b) the growth of Asian sea bass is primarily limited by NO_3, which is the most prevalent nutrient. The recorded levels of nitrite in the culture systems, ranging from 0.2 to 12 mg l^{-1}, are deemed to be within a safe range Our model prediction is further supported by this, indicating that seawater with low NO_3 concentrations had a low likelihood of being a suitable site (Mohammed Ashraful Haque, 2019). Asian sea bass can be reared in sea enclosures strategically located at the entrances of rivers or estuaries, providing both the open sea and the neighboring lagoon with sufficient shelter against direct wave impact and other external factors (Araujo et al., 2022). Our analysis indicates that the waves are of moderate intensity in the Bakkali and Naf channels, making this area an ideal site for cultivating the species.

Our predictive model indicates that the southeastern coastal waters of Bangladesh present a favorable environment for the establishment of an Asian sea bass habitat. In the juvenile phase, we evaluate the eating patterns of Asian sea bass by analyzing the prevalence of secondary food sources like zooplankton in the adjacent water (Chaklader et al., 2015;).

In this particular setting, we have noted the existence of megalopa, fish larvae, and shrimp larvae, all of which act as nourishment for the Asian sea bass(Kamruzzaman et al., 2015). The probability of finding the high Asian sea bass in this region is determined by the presence of favorable environmental conditions.

The study highlights the Cox's Bazar coast in the southeast zone as an ideal habitat for sea bass due to several favorable factors. These factors include moderate turbidity, optimal salinity levels, moderate depth, and abundant nutrients. With the increasing importance of aquaculture in Bangladesh, particularly in sustaining livelihoods and contributing to the economy, the sea bass has emerged as a promising species for aquaculture. This is due to its rapid growth rate, adaptability to artificial feed or trash fish, and its capacity to be bred in captivity.

Given the significance of sea bass farming and the need for sustainable aquaculture development, it is crucial to carefully select appropriate locations. The proposed solution is the creation of a marine spatial plan, which is a strategic approach to managing and allocating marine resources. In this context, the habitat map generated in the research becomes a valuable tool for formulating a marine spatial plan specifically tailored for the establishment of Asian sea bass in the Cox's Bazar region.

A marine spatial plan involves systematic planning and allocation of marine areas for various uses, taking into account ecological, economic, and social factors. In the case of Asian sea bass aquaculture, the habitat map can guide decision-makers in identifying suitable areas for farming operations. This ensures compatibility with environmental conditions and minimizes potential negative impacts. Such an approach contributes to the sustainable development of aquaculture, aligning with broader goals of economic growth, livelihood support, and environmental conservation in the coastal community of Cox's Bazar.

6. Conclusion:

In conclusion, our model's prediction has identified the Bakkhali and Naf river channel as the most suitable site for Asian sea bass aquaculture. However, it is important to note that the mouth of the estuary and areas with less depth are not as suitable for this purpose. This study represents an initial effort to determine the optimal location for Asian sea bass, taking into account all the necessary environmental factors that affect their growth and distribution. By doing so, our study will contribute directly to the development of the Blue Economy in the country, leading to economic benefits and improved livelihoods for coastal communities.

A site suitability map for Asian sea bass can be used to guide conservation strategies during the breeding, spawning, and larval development stages of the species in the estuaries of Bakkhali and Naf rivers. The selected areas with a high probability of success can be effectively regulated and enforced through the proper implementation of laws. Additionally, our study has laid the foundation for further research concepts that are crucial for advancing commercial aquaculture in the coastal area of Cox's Bazar. During the culture period, it is essential to study the food and feeding behaviors of Asian sea bass in order to conduct research on aquaculture.

References

i. AftabUddin, S., Hussain, M. G., Abdullah Al, M., Failler, P., & Drakeford, B. M. (2021). On the potential and constraints of mariculture development in Bangladesh. *Aquaculture International*, *29*(2), 575–593. https://doi.org/10.1007/s10499-020-00643-9

ii. Araujo, G. S., Silva, J. W. A. da, Cotas, J., & Pereira, L. (2022). Fish Farming Techniques: Current Situation and Trends. *Journal of Marine Science and Engineering*, *10*(11), 1598. https://doi.org/10.3390/jmse10111598

iii. Boonyaratpalin, M. (1997). Nutrient requirements of marine food fish cultured in Southeast Asia. *Aquaculture*, *151*(1–4), 283–313. https://doi.org/10.1016/S0044-8486(96)01497-4

iv. Chaklader, Md. R., Siddik, M. A. B., & Nahar, A. (2015). Taxonomic Diversity of Paradise Threadfin Polynemus paradiseus (Linnaeus, 1758) Inhabiting Southern Coastal Rivers in Bangladesh. *Sains Malaysiana*, *44*(9), 1241–1248. https://doi.org/10.17576/jsm-2015-4409-04

v. Cheung, W. W. L., Watson, R., & Pauly, D. (2013). Signature of ocean warming in global fisheries catch. *Nature*, *497*(7449), 365–368. https://doi.org/10.1038/nature12156

vi. Coastal set bagnet fishery in the Payra river, Bangladesh and its impact on fisheries and biodiversity. (2015). *Journal of Coastal Life Medicine*. https://doi.org/10.12980/JCLM.3.2015JCLM-2014-0121

vii. DikMA, I. S. (2016). Barramundi, Lates calcarifer (Bloch, 1790): A New Dimension to the Fish Farming in Coastal Bangladesh. *Journal of Aquaculture Research & Development*, 10–13.

viii. Elith*, J., H. Graham*, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A., J. Hijmans, R., Huettmann, F., R. Leathwick, J., Lehmann, A., Li, J., G. Lohmann, L., A. Loiselle, B., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., McC. M. Overton, J., Townsend Peterson, A., … E. Zimmermann, N. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, *29*(2), 129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x

ix. Fadlaoui, S., El Asri, O., Bouterfas, M., & Melhaoui, M. (2021). Effects of Physicochemical Variables of Superficial Waters on the Abundance of the North African Freshwater Crab Potamon algeriense (Bott, 1967). *Journal of Toxicology*, *2021*, 1–13. https://doi.org/10.1155/2021/6669919

x. Graham, M. H. (2003). CONFRONTING MULTICOLLINEARITY IN ECOLOGICAL MULTIPLE REGRESSION. *Ecology*, *84*(11), 2809–2815. https://doi.org/10.1890/02-3114

xi. Guisan, A., Edwards, T. C., & Hastie, T. (2002). Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecological Modelling*, *157*(2–3), 89–100. https://doi.org/10.1016/S0304-3800(02)00204-1

xii. Hajirezaee, S., Ajdari, D., Matinfar, A., Hosseini Aghuzbeni, S. H., & Rafiee, G. R. (2015). A preliminary study on marine culture of Asian sea bass, *Lates calcarifer* in the coastal earthen ponds of Gwadar region, Iran: an assessment of growth parameters, feed intake efficiency and survival rate. *Journal of Applied Animal Research*, *43*(3), 309–313. https://doi.org/10.1080/09712119.2014.963105

xiii. Hanif MA, S. M. C. M. N. A. M. S. (2015). Fish diversity in the southern coastal waters of BangladeshPresent status, threats and conservation perspectives. *Croat J Fish*.

xiv. Haque, M. A., Hossain, M. I., Uddin, S. A., & Dey, P. K. (2020). Review on distribution, culture practices, food and feeding, brood development and artificial breeding of Seabass, Lates calcarifer (BLOCH 1790): Bangladesh perspective. *Research in Agriculture Livestock and Fisheries*, *6*(3), 405–414. https://doi.org/10.3329/ralf.v6i3.44806

xv. Haque, M. A., Hossain, Md. I., Aftabuddin, S., Habib, A., & Siddique, M. A. M. (2021). First onboard fertilization of Asian seabass, Lates calcarifer: Effects of egg stocking density on the fertilization, hatching and survival rate. *Scientific African*, *12*, e00841. https://doi.org/10.1016/j.sciaf.2021.e00841

xvi. Hastie, T., & Tibshirani, R. (1986). Generalized Additive Models. *Statistical Science*, *1*(3). https://doi.org/10.1214/ss/1177013604

xvii. Hossain, M. A. R. (2015). An overview of Fisheries sector of Bangladesh. *Research in Agriculture Livestock and Fisheries*, *1*(1), 109–126. https://doi.org/10.3329/ralf.v1i1.22375

xviii. Irmawati, I., Umar, Moh. T., Ambo Ala Husain, A., Citra Malina, A., Nurdin Kadir, N., & Alimuddin, A. (2020). Distribution and characteristics of Asian seabass (Lates calcarifer Bloch, 1790) in South Sulawesi. *IOP Conference Series: Earth and Environmental Science*, *564*(1), 012011. https://doi.org/10.1088/1755-1315/564/1/012011

xix. Irmawati, Malina, A. C., Husain, A. A. A., Annisa, A. R., Kadriah, I. A. K., & Alimuddin, A. (2021). Genetic variation in the Asian seabass (Lates calcarifer Bloch, 1790) from Wallacea Region estimated using random amplified polymorphic DNA (RAPD) markers. *IOP Conference Series: Earth and Environmental Science*, *763*(1), 012010. https://doi.org/10.1088/1755-1315/763/1/012010

xx. Jerry, D. R. (Ed.). (2013). *Biology and Culture of Asian Seabass Lates Calcarifer*. CRC Press. https://doi.org/10.1201/b15974

xxi. Kamruzzaman, S., Al Noor, S. M., & Hossain, M. D. (2015). Food and feeding habits of Juvenile white sea bass, Lates Calcarifer (Bloch) from the Shibsha river in the South-

Western coastal region of Bangladesh. *Journal of Bio-Science*, *21*, 141–144. https://doi.org/10.3329/jbs.v21i0.22528

xxii. Klaus Riede. (2004). “Global register of migratory species - From global to regional scales.,.” *Federal Agency for Nature Conservation, Bonn, Germany*.

xxiii. Konovalov, D. A., Saleh, A., Domingos, J. A., White, R. D., & Jerry, D. R. (2018). Estimating Mass of Harvested Asian Seabass Lates calcarifer from Images. *World Journal of Engineering and Technology*, *06*(03), 15–23. https://doi.org/10.4236/wjet.2018.63B003

xxiv. Lewis, E. L., & Perkin, R. G. (1981). The practical salinity scale 1978: conversion of existing data. *Deep Sea Research Part A. Oceanographic Research Papers*, *28*(4), 307–328. https://doi.org/10.1016/0198-0149(81)90002-9

xxv. MAB, S., MA, I., MA, H., MR, C., & R, K. (2016a). Barramundi, Lates calcarifer (Bloch, 1790): A New Dimension to the Fish Farming in Coastal Bangladesh. *Journal of Aquaculture Research & Development*, *7*(12). https://doi.org/10.4172/2155-9546.1000461

xxvi. MAB, S., MA, I., MA, H., MR, C., & R, K. (2016b). Barramundi, Lates calcarifer (Bloch, 1790): A New Dimension to the Fish Farming in Coastal Bangladesh. *Journal of Aquaculture Research & Development*, *7*(12). https://doi.org/10.4172/2155-9546.1000461

xxvii. Mathew Grace. (2009). Taxonomy, identification and biology of Seabass (Lates calcarifer). *National Training on ’Cage Culture of Seabass*, 39–55.

xxviii. Md. Amirul Islam, Aovijite Bosu, Md. Monjurul Hasan, Farhana Yasmin, Abu Bakker Siddique Khan, Mousumi Akhter, Md. Rahamat Ullah, Ehsanul Karim, Md. Harunor Rashid, & Yahia Mahmud. (2023a). Culture technique of seabass, Lates calcarifer in Asia: A review. *International Journal of Science and Technology Research Archive*, *4*(1), 006–017. https://doi.org/10.53771/ijstra.2023.4.1.0174

xxix. Md. Amirul Islam, Aovijite Bosu, Md. Monjurul Hasan, Farhana Yasmin, Abu Bakker Siddique Khan, Mousumi Akhter, Md. Rahamat Ullah, Ehsanul Karim, Md. Harunor Rashid, & Yahia Mahmud. (2023b). Culture technique of seabass, Lates calcarifer in Asia: A review. *International Journal of Science and Technology Research Archive*, *4*(1), 006–017. https://doi.org/10.53771/ijstra.2023.4.1.0174

xxx. Md. Amirul Islam, Aovijite Bosu, Md. Monjurul Hasan, Farhana Yasmin, Abu Bakker Siddique Khan, Mousumi Akhter, Md. Rahamat Ullah, Ehsanul Karim, Md. Harunor Rashid, & Yahia Mahmud. (2023c). Culture technique of seabass, Lates calcarifer in Asia: A review. *International Journal of Science and Technology Research Archive*, *4*(1), 006–017. https://doi.org/10.53771/ijstra.2023.4.1.0174

xxxi. MM, A. S. N. D. M., & N. D. Monwar. (2013). polyculture of seabass with tilapia for the utilization of brown fields in the coastal areas of Cox's Bazar, Bangladesh. *International Journal of Fisheries and Aquaculture*, 12–23.

xxxii. Mohd Nor, N., Mohd Yazid, S. H., Mohd Daud, H., Azmai, M. N. A., & Mohamad, N. (2019). Costs of management practices of Asian seabass (Lates calcarifer Bloch, 1790) cage culture in Malaysia using stochastic model that includes uncertainty in mortality. *Aquaculture*, *510*, 347–352. https://doi.org/10.1016/j.aquaculture.2019.04.042

xxxiii. Mushahida-Al-Noor, S., Kamruzzaman, S., & Hossain, Md. D. (2013). Seasonal Variation of Food composition and Feeding Activity of Small Adult Barramundi (Lates calcarifer, Bloch) in the South west Coastal Water near Khulna, Bangladesh. *Our Nature*, *10*(1), 119–127. https://doi.org/10.3126/on.v10i1.7772

xxxiv. Sarker, S., Akter, M., Rahman, M. S., Islam, M. M., Hasan, O., Kabir, Md. A., & Rahman, M. M. (2021). Spatial prediction of seaweed habitat for mariculture in the coastal area of Bangladesh using a Generalized Additive Model. *Algal Research*, *60*, 102490. https://doi.org/10.1016/j.algal.2021.102490

xxxv. Simpson, G. L. (2018). Modelling Palaeoecological Time Series Using Generalised Additive Models. *Frontiers in Ecology and Evolution*, *6*. https://doi.org/10.3389/fevo.2018.00149

xxxvi. Venkatachalam, S., Kandasamy, K., Krishnamoorthy, I., & Narayanasamy, R. (2018a). Survival and growth of fish (Lates calcarifer) under integrated mangrove-aquaculture and open-aquaculture systems. *Aquaculture Reports*, *9*, 18–24. https://doi.org/10.1016/j.aqrep.2017.11.004

xxxvii. Venkatachalam, S., Kandasamy, K., Krishnamoorthy, I., & Narayanasamy, R. (2018b). Survival and growth of fish (Lates calcarifer) under integrated mangrove-aquaculture and open-aquaculture systems. *Aquaculture Reports*, *9*, 18–24. https://doi.org/10.1016/j.aqrep.2017.11.004

xxxviii. Williams, K. C., Barlow, C. G., Rodgers, L., Hockings, I., Agcopra, C., & Ruscoe, I. (2003). Asian seabass Lates calcarifer perform well when fed pelleted diets high in protein and lipid. *Aquaculture*, *225*(1–4), 191–206. https://doi.org/10.1016/S0044-8486(03)00278-3