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Operationalizing Habitat Suitability Modeling into a Web-Based System for Predicting Skipjack Tuna Fishing Grounds

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ABSTRACT

Habitat suitability modeling is frequently used to identify fishing grounds, yet its outputs often remain confined to scientific publications rather than operational systems. This study developed FishPost (Fishing Prediction and Oceanographic Spatial Tool), a web-based platform that operationalizes skipjack tuna habitat models into an interactive spatial tool. The system integrates monthly Habitat Suitability Index (HSI) maps derived from a Generalized Additive Model (GAM) covering Fisheries Management Areas 573, 713, and 714. Key environmental predictors include sea surface temperature, sea surface height, salinity, and current velocity. FishPost enables users to visualize spatial HSI distributions and evaluate fishing zone potential through both geographic coordinate extraction and environmental parameter inputs. By transforming complex scientific models into a digital interface, FishPost bridges the gap between research and practical fisheries management, representing a significant step toward the digitalization of oceanographic data for operational use.

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INTRODUCTION

The spatial distribution of pelagic fish, including skipjack tuna (*Katsuwonus pelamis*), is strongly influenced by the dynamics of oceanographic parameters such as sea surface temperature, chlorophyll-a, salinity, and ocean currents. Variations in these parameters affect ocean productivity, food availability, and migration patterns of pelagic fish in the open ocean (Basilone *et al*., 2013; Gaol *et al*., 2014; Chen *et al*., 2020; Ngando *et al*., 2020). Several studies have also shown that changes in oceanographic conditions such as sea surface temperature, salinity, and ocean currents play an important role in determining the distribution and abundance of skipjack tuna in the Indian Ocean (Ma'mun *et al*., 2019; Pratama *et al*., 2022; Siringoringo *et al*., 2024). Therefore, environmental parameter–based approaches are widely used to identify potential fishing grounds.

One commonly used approach in fish distribution studies is the *Habitat Suitability Index* (HSI), which integrates the relationship between environmental variables and fish presence in the form of habitat suitability probabilities. HSI models enable the analysis of spatial relationships between oceanographic conditions and fish distribution, allowing the prediction of potential fishing grounds (Pratama *et al*., 2025; Yati *et al*., 2024). In this study, habitat modeling was conducted using the *Generalized Additive Model* (GAM), which is capable of flexibly representing nonlinear relationships between oceanographic variables and habitat suitability.

Although many fishing ground prediction models have been developed, their operational application remains limited. The outputs of these models are generally presented as static maps in scientific publications, making them difficult to access and utilize by field users such as fishers or fisheries managers. In fact, information on fishing ground prediction is crucial for improving fishing efficiency, optimizing search time for fish, and reducing fuel consumption (Tilik *et al*., 2014).

Transforming scientific models into web-based information systems is one approach to bridge the gap between research outputs and their practical application in the field. Web-based systems enable interactive spatial visualization, rapid evaluation of environmental conditions, and broader access to prediction information for users. Based on this background, this study aims to develop FishPost (*Fishing Prediction and Oceanographic Spatial Tool*), a web-based fishing ground prediction system that integrates the outputs of a skipjack tuna HSI model based on the *Generalized Additive Model*(GAM) for Fisheries Management Areas (FMA) 573, 713, and 714. The system displays monthly prediction layers and provides a module for evaluating water potential based on environmental parameters entered by users.

THEORETICAL REVIEW

Spatial Distribution of Pelagic Fish and the Role of Oceanographic Parameters

The spatial distribution of pelagic fish, including skipjack tuna (*Katsuwonus pelamis*), is strongly influenced by the dynamics of oceanographic parameters such as sea surface temperature, chlorophyll-a, salinity, and ocean currents (Pratama et al., 2022; Pratama et al., 2025; Muhyun et al., 2025).

Variations in these parameters determine ocean productivity, food availability, and migration patterns of pelagic fish in the open ocean (Basilone et al., 2013; Gaol et al., 2014; Chen et al., 2020; Ngando et al., 2020). Changes in oceanographic conditions have been shown to play an important role in determining the distribution and abundance of skipjack tuna, making environment-based approaches widely used for identifying potential fishing grounds.

Ecologically, pelagic fish tend to concentrate in areas with optimal environmental conditions, such as suitable temperatures, favorable water mass dynamics, and the accumulation of prey (Saifuddin et al., 2014; Ma'mun et al., 2019). Therefore, understanding the relationship between oceanographic parameters and fish distribution is fundamental for developing fishing ground prediction models.

Habitat Suitability Index (HSI) in Fisheries Studies

The Habitat Suitability Index (HSI) is a quantitative approach used to describe the suitability level of a habitat for pelagic fish based on oceanographic conditions (Pratama et al., 2022). HSI integrates multiple environmental variables into a single index ranging from 0 to 1, where higher values indicate more optimal habitat suitability (Phillips & Dudik, 2008). In fisheries studies, HSI is widely used to analyze spatial relationships between oceanographic conditions and fish presence, as well as to predict potential fishing grounds (Pratama et al., 2022; Pratama et al., 2025). This approach enables the transformation of environmental data into more applicable information for decision-making in fishing activities.

Generalized Additive Model (GAM) in Habitat Modeling

The Generalized Additive Model (GAM) is a statistical approach commonly used in species distribution modeling, including fish habitat studies. GAM allows for modeling nonlinear relationships between the response variable (e.g., fish presence) and predictor variables (environmental parameters) through smooth functions (Zuur et al., 2009).

Mathematically, GAM is expressed as a combination of an intercept and smooth functions of predictor variables, providing high flexibility in capturing complex relationships. In fisheries habitat studies, this approach is considered superior to conventional linear models because it can represent ecological responses that are not strictly linear to environmental changes (Mugo et al., 2010; Sasmito et al., 2022). The application of GAM in HSI modeling enables more realistic estimation of habitat suitability probabilities, thereby improving the accuracy of fish distribution predictions.

Web-Based Information Systems in Fisheries

Advances in information technology enable habitat modeling outputs to be integrated into web-based information systems. Such systems enhance usability and accessibility for various stakeholders, including fishers and fisheries managers (Pratama et al., 2020).

In the context of this study, the development of a web-based system such as FishPost represents the operationalization of scientific models into an applicable platform. The system not only displays habitat suitability maps but also provides features for evaluating water conditions based on user-input coordinates and environmental parameters. This approach demonstrates that the integration of habitat modeling and information systems can function as a decision support system in capture fisheries.

METHODOLOGY

Research Design and System Development

This study employs a research and development (R&D) approach aimed at operationalizing a Generalized Additive Model (GAM)-based Habitat Suitability Index (HSI) into a web-based fishing ground prediction information system. The statistical models utilized in the system were previously developed and validated in earlier studies (Muhyun et al., 2025; Pratama et al., 2025); therefore, this research focuses on the integration of these models into an operational platform, spatial visualization, and the development of modules for evaluating aquatic conditions. The research flowchart is presented in Figure 1.

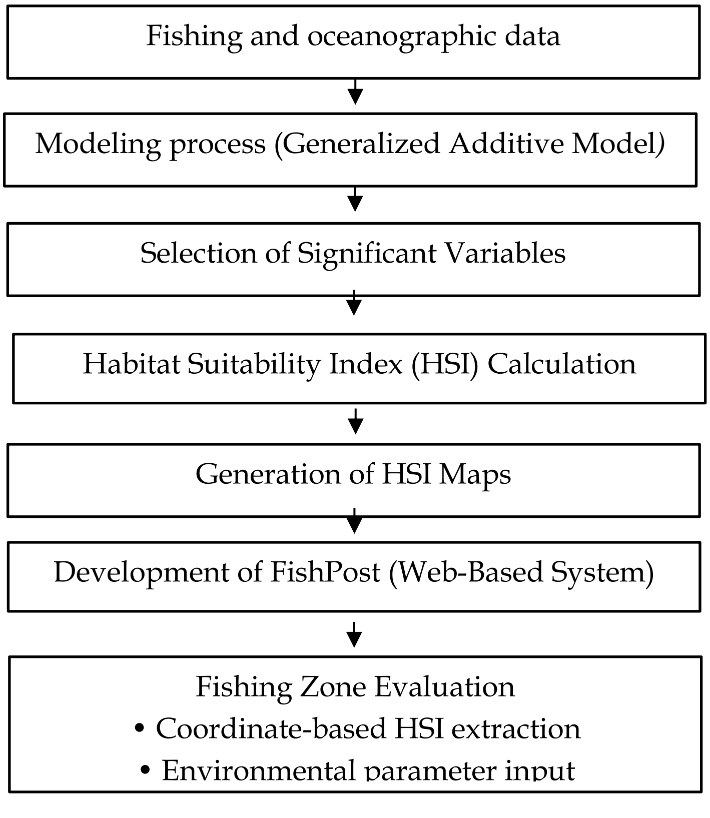

Figure 1. Flowchart of the research methodology for the development of the FishPost system.

The system development stages consist of several key steps, including the extraction of HSI model outputs, data conversion into operational raster formats, system architecture design, implementation of interactive map visualizations, and the development of evaluation modules based on environmental parameters. Once the system development was complete, functionality testing was conducted to ensure that all system components operated correctly (Alfiani et al., 2023; Darmanto et al., 2022).

Habitat Suitability Index Model

The Habitat Suitability Index (HSI) model utilized in the FishPost system was constructed using the Generalized Additive Model (GAM) approach. This model is employed to represent the relationship between skipjack tuna presence and the marine environmental parameters that influence habitat suitability, using the following mathematical formula (Ding et al., 2025; Sasmito et al., 2022):

$$g(\mu_i)= \beta_0 + s_1(X_{1i}) + s_2(X_{2i}) + \cdots + s_k(X_{ki})$$

where:

$g(\mu_i)$ = The link function of the expected response at observation
β_0 = the model intercept
$s_k(\cdot)$ = the smooth function of the *k* variable
Xk_i = the value of the *k* environmental variable at the *i* observation

In the modeling stage, several oceanographic variables were used as predictors, namely sea surface temperature, chlorophyll-a, salinity, sea surface height, current velocity, and bathymetry. These variables were selected because they are ecologically related to aquatic productivity, water mass dynamics, and the habitat conditions of pelagic fish. Within the GAM framework, the relationship between fish presence probability and environmental variables was modeled using smooth functions to represent non-linear relationships between environmental variables and fish distribution. The model output consists of habitat suitability probability values ranging from 0 to 1, which are then used as the Habitat Suitability Index (Tugores et al., 2011).

Significant Variable Selection and Habitat Suitability Index Output

Model analysis results showed that not all environmental variables provided a significant influence on skipjack tuna distribution. Based on the model selection results, the variables proven to be significant were sea surface temperature (SST), sea surface height (SSH), salinity, and current velocity. Conversely, chlorophyll-a and bathymetry variables did not show a significant influence in the model and thus were not used in the aquatic potential evaluation calculations in the FishPost system. Nevertheless, both variables were still used in the initial modeling stage to ensure that all relevant variables were considered in the analysis process.

The GAM model output is in the form of habitat suitability probability rasters which were then converted into GeoTIFF format for system implementation purposes. The raster layers were arranged into twelve monthly layers representing the distribution of habitat suitability from January to December. Each layer stores HSI values in the range of 0 to 1 in the FMA 573, 713, and 714 regions. These monthly layers were then integrated into the FishPost system as the basis for visualizing fishing ground prediction maps.

FishPost System Architecture

FishPost was developed as a web-based application using the R programming language with the Shiny framework. The system is designed using a three-tier architecture consisting of a data layer, an application logic layer, and a presentation layer. The data layer functions as storage for GeoTIFF raster files containing monthly Habitat Suitability Index (HSI) predictions and response curve data from the Generalized Additive Model (GAM). The application logic layer is responsible for the process of calling raster layers, extracting pixel values based on user coordinates, and evaluating environmental parameters against the model response curves. The presentation layer is the user interface that displays interactive maps, coordinate and environmental parameter input forms, and zone evaluation result indicators. In the system development process, several spatial processing packages such as raster, terra, and leafletwere used for raster data processing and interactive map visualization.

The evaluation of zone potential is carried out through two approaches, namely based on geographic coordinates and environmental parameters entered by the user. Coordinate-based evaluation is performed by extracting HSI raster pixel values at locations corresponding to the latitude and longitude coordinates input by the user using the nearest raster cell extraction method. The HSI value obtained is then compared with a threshold value to determine the classification of potential or non-potential zones. In this study, the habitat suitability threshold was set based on the habitat probability generated by the GAM model, where is categorized as a potential zone, while is categorized as a non-potential zone (Pratama et al., 2025).

Zone Potential Evaluation on the FishPost System

FishPost provides a zone evaluation feature based on geographic coordinates entered by the user. The system extracts the Habitat Suitability Index (HSI) value at the raster pixel corresponding to those coordinates and then compares it with a certain threshold to determine the zone status. Locations with HSI values above the threshold are classified as potential zones, while values below the threshold are classified as non-potential zones. This approach allows the conversion of raster-based spatial information into point information that can be used directly by users to evaluate fishing potential at specific locations.

In addition to raster-based evaluation, FishPost also provides an aquatic potential evaluation module based on environmental parameters entered by the user. The parameters used include sea surface temperature, sea surface height, salinity, and current velocity, which are significant variables in the GAM model. These parameter values are compared with the response curves of each variable to determine the relative level of habitat suitability. Based on this evaluation, the system then classifies the aquatic conditions as a potential or non-potential zone.

RESULTS

Spatial Distribution of Habitat Suitability Index

The performance of the Generalized Additive Model (GAM), which serves as the basis for the development of FishPost, has been evaluated in previous studies. The model demonstrated good predictive capability, with relatively high values of Area Under the Curve (AUC) and True Skill Statistic (TSS) within the study area. A summary of model performance is presented in Table 1.

Table 1. Performance of the GAM-based habitat suitability models used as the basis for FishPost

Fishing Ground Area	AUC	AUC Average	TSS	TSS Average	Reference
FMA 573	0.814-0.930	0.8806	0.540-0.760	0.6717	Pratama et al., 2025
FMA 713 and 714	0.76 – 0.92	0.845	0.54 - 0.77	0.660	Muhyun et al., 2025

The Generalized Additive Model (GAM) produced Habitat Suitability Index (HSI) maps that illustrate the spatial distribution of skipjack tuna habitat suitability within Fisheries Management Areas (FMAs) 573, 713, and 714. HSI values range from 0 to 1, where higher values indicate greater habitat suitability for the presence of skipjack tuna. An example of the spatial distribution of HSI generated by the GAM model is presented in Figure 2.

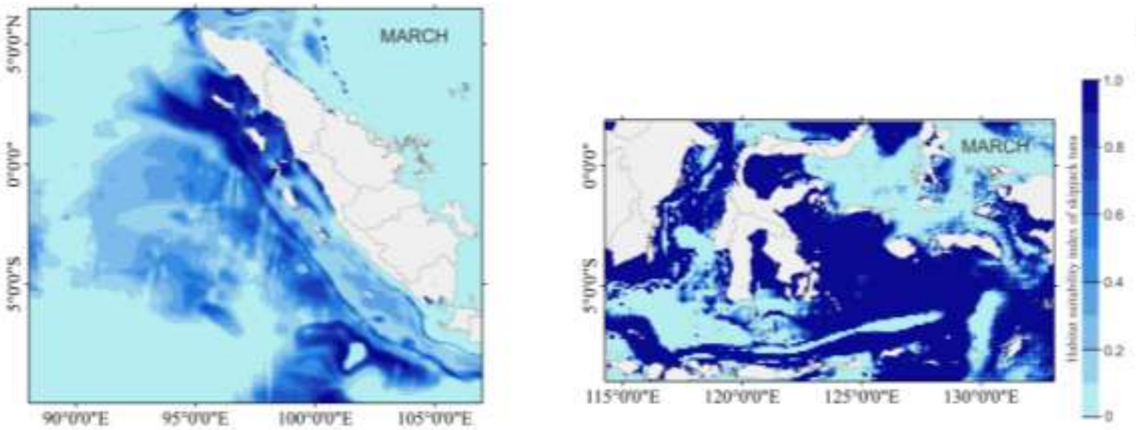

Figure 2. Spatial distribution of Habitat Suitability Index FMA 573, 713, and 714

Spatial Distribution of Habitat Suitability Index (HSI)

The spatial distribution of the Habitat Suitability Index (HSI) reveals heterogeneous patterns of habitat suitability across Fisheries Management Areas (FMAs) 573, 713, and 714. HSI values range from 0 to 1, with higher values indicating greater habitat suitability for the presence of skipjack tuna. In several offshore areas, HSI values are relatively high (>0.7), suggesting more favorable oceanographic conditions for skipjack habitat. In contrast, some coastal areas exhibit lower HSI values (<0.4), indicating less optimal environmental conditions for the distribution of this species.

This distribution pattern indicates that skipjack habitat suitability is not spatially uniform and is strongly influenced by the dynamics of oceanographic parameters such as sea surface temperature, sea surface height, salinity, and current velocity. This spatial variability provides insight into areas that have the potential to become more productive fishing grounds.

Evaluation of Potential Fishing Zones

FishPost provides two approaches for evaluating potential fishing grounds. The first approach is based on HSI values at specific locations, obtained through raster pixel value extraction using user-provided coordinates. The extracted HSI values are then compared with predefined thresholds within the system to determine whether a location is classified as a potential or non-potential fishing zone.

The second approach is based on environmental parameters input by the user. In this approach, the input environmental values are compared with the response curves derived from the GAM model to assess relative habitat suitability. Based on this evaluation, the system classifies the water conditions as either potential or non-potential zones. The combination of these two approaches enables users to obtain information on fishing ground potential based on both spatial model predictions and directly observed environmental conditions.

Implementation of the FishPost System

The HSI model outputs are subsequently integrated into the FishPost system, which is developed as a web-based platform for predicting potential fishing grounds. The system enables interactive visualization of HSI maps and provides modules for evaluating fishing zone potential. The interface of the FishPost system is presented in Figure 3.

Figure 3. FishPost system interface

The system interface consists of several main components, including the fishing coordinate input module (area A), environmental parameter input module (area B), zone evaluation results (areas C and D), and an interactive HSI map (area E). The interactive map displays the spatial distribution of HSI across the study area, while the coordinate input module allows users to evaluate fishing potential at specific locations by entering latitude and longitude values.

In addition, the system provides an environmental parameter input module that allows users to enter values for sea surface temperature, sea surface height, salinity, and current velocity. These parameters are then used to evaluate the level of habitat suitability based on response functions derived from the previously published GAM model.

DISCUSSION

The research results demonstrate that the Generalized Additive Model (GAM)-based Habitat Suitability Index (HSI) model can be effectively integrated into a web-based information system to support skipjack tuna fishing ground predictions. The HSI values generated by the model describe spatial variations in habitat suitability influenced by the dynamics of oceanographic parameters such as sea surface temperature, sea surface height, salinity, and current velocity. These variations indicate that skipjack tuna habitat distribution is dynamic and heavily influenced by marine environmental conditions (Ma'mun et al., 2019; Suhermat, 2023). The GAM approach allows for a more realistic representation of non-linear relationships between environmental variables and fish presence compared to conventional linear models (Chen et al., 2021; Sasmito et al., 2022).

The performance of the GAM model used in this study was evaluated in previous research (Pratama et al., 2025; Muhyun et al., 2025) and showed good predictive capability with relatively high AUC and TSS values in the study area. The average AUC values of 0.8806 in FMA 573 and 0.845 in FMA 713–714 indicate that the model has a strong discriminatory ability to distinguish between suitable and unsuitable habitat areas. Similarly, the average TSS values of 0.6717 and 0.660 show a high level of classification accuracy. These values demonstrate that the model serving as the foundation for FishPost development possesses sufficient reliability for use in a fishing ground prediction system.

The integration of HSI model outputs into the FishPost system shows that habitat modeling results can be used not only for scientific analysis but can also be operationalized into an information system directly accessible to users. Most habitat modeling research concludes at the stage of model performance evaluation and the presentation of analysis maps. In this study, the modeling results are integrated into a web-based system that enables interactive spatial visualization and direct evaluation of aquatic conditions through coordinate and environmental parameter inputs (Handiani & Heriati, 2020; Radiarta et al., 2013). This approach demonstrates the potential of utilizing habitat models as the basis for developing decision support systems in fishing activities.

The presence of two evaluation approaches within the FishPost system—spatial HSI value evaluation and environmental parameter evaluation—provides flexibility for users in assessing the potential of a fishing location. HSI-based evaluation represents the integration of all environmental variables within a monthly spatial domain, while environmental parameter-based evaluation allows for an assessment of aquatic conditions based on values observed directly in the field. The differences in results that may arise between the two approaches reflect the difference in scale between spatial model predictions and actual environmental conditions.

Although the FishPost system has successfully integrated habitat models into an operational platform, further development is still required to enhance system functionality. One existing limitation is the use of static monthly HSI layers that are not yet automatically updated due to limited availability of consistent daily oceanographic data. Future development could be directed toward the integration of oceanographic data with higher temporal resolution to enable more dynamic prediction updates.

Overall, FishPost demonstrates that habitat modeling results can be operationalized into an information system that supports the utilization of oceanographic data in capture fisheries. This system functions not only as a map visualization tool but also as a platform for evaluating aquatic conditions that can assist users in determining potential fishing grounds (Mubarak, 2023; Purwanto & Ramadhani, 2020).

CONCLUSIONS AND RECOMMENDATIONS

This study successfully developed FishPost (Fishing Prediction and Oceanographic Spatial Tool), a web-based information system that integrates Generalized Additive Model (GAM)-based Habitat Suitability Index (HSI) outputs to support skipjack tuna fishing ground predictions in FMA 573, 713, and 714. The system displays monthly HSI maps in raster format and provides two approaches for evaluating fishing area potential: based on HSI values at specific coordinates and based on user-inputted environmental parameters.

The integration of habitat models into a web platform enables interactive spatial visualization and direct evaluation of aquatic conditions by users. By utilizing significant environmental parameters from the model—namely sea surface temperature, sea surface height, salinity, and current velocity—FishPost provides more accessible and understandable information on fishing ground potential. The development of this system demonstrates that validated statistical models can be operationalized into information systems that support the utilization of oceanographic data in capture fisheries activities.

FURTHER STUDY

Future research should focus on integrating real-time oceanographic data feeds and higher temporal resolution to enhance the system's dynamic predictive accuracy for daily fishing operations.

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