Analysis of habitat characteristics of small pelagic fish based on generalized additive models in Kepulauan Seribu Waters

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Abstract. One of the required information for sustainable fisheries management is about the habitat characteristics of a fish species. This information can be used to map the distribution of fish and map the potential fishing ground. This study aimed to analyze the habitat characteristics of small pelagic fishes (anchovy, squid, sardine and scads) which were mainly caught by lift net in Kepulauan Seribu waters. Research on habitat characteristics had been widely done, but the use of total suspended solid (TSS) parameters in this analysis is still lacking. TSS parameter which was extracted from Landsat 8 along with five other oceanographic parameters, CPUE data and location of fishing ground data from lift net fisheries in Kepulauan Seribu were included in this analysis. This analysis used Generalized Additive Models (GAMs) to evaluate the relationship between CPUE and oceanographic parameters. The results of the analysis showed that each fish species had different habitat characteristics. TSS and sea surface height had a great influence on the value of CPUE from each species. All the oceanographic parameters affected the CPUE of each species. This study demonstrated the effective use of GAMs to identify the essential habitat of a fish species.

1. Introduction

The distribution of fisheries resources varies according to their species and their preferred habitat. The distribution of fisheries resources have a specific pattern, such as small pelagic fishes are converged on specific chlorophyll concentrations and temperature [1]. Fish tend to distribute in areas that are good for spawning, feeding and growing during their life cycle. Also, the distribution of resources is also affected by other factors, such as the fish behavior and the dynamics of the population [2]. Identification of important areas that have high fish distribution is one way to support the ecosystem approach to fisheries management (EAFM) and then will also support the sustainability of a fishery resource. Information of the distribution of fisheries resources can be obtained by analyzing the relationship between the fish distribution and the oceanographic characteristics of an area. This is because there is a significant correlation between the distributions of fishes with their environmental [3].

Analysis of habitat characteristics can provide information about habitat characteristics which were favored by fish. This kind of information can be used to obtain important areas to fish, fish distribution and areas with high abundance of fish resource. Analysis of fish habitat characteristics had been widely done before. Some previous studies used a statistical approach to determine the abundance of certain fish species [1, 4] and to map the hotspots of certain fish species [5, 6]. These studies analyzed of habitat characteristics by evaluating the relationship between the presences of fishes with oceanographic parameters in an area. Various oceanographic parameters had been analyzed in these studies, such as sea surface temperature and chlorophyll-*a* concentration. Total suspended solid is one of the oceanographic parameters that affect the distribution of fish, especially in coastal waters and estuaries. [7] reported that the changes in total suspended solid concentration may affect the growth and development of fish. However, TSS parameter is still not widely used as one of the oceanographic parameters in habitat characteristic analysis so that the information of TSS on fish distribution is lacking. Since TSS were assumed to affect the fish distribution, TSS along with the other oceanographic parameters were included in the analysis of habitat characteristics in this study. The addition of TSS in this analysis was one of the novelty in this research.

Analysis of habitat characteristics of fish can be done by using a statistical approach. There are several statistical approaches that can be used and one of them is generalized additives models (GAMs). Some previous studies had used GAMs and reported that this method could effectively analyze the relationship between oceanographic parameters and fish abundance in a waters [6, 8, 9]. GAMs utilize a non-linear and non-parametric technique to analyze the relationship between the variable response and the explanatory variables, which are highly non-linear and non-monotonic [10, 12].

Data of oceanographic parameters have been widely available from various sources by utilizing a variety of technologies, such as satellite remote sensing technology. Utilization of this technology can provide an effective way for monitoring and managing an area. This technology can provide information within a large area in a periodical time. In using data from satellite remote sensing technology, some constraints can be encountered, such as the accuracy need to be improved and the processing of data which require advanced skills. However, with the availability of such information, allowed us to identify the oceanographic characteristics of preferred habitat by a specific fish. With the availability of fisheries information, such as catch data, fishing locations data and oceanographic data,combined with statistical approaches, better information about the distribution of fishery resources can be obtained.

Kepulauan Seribu is an archipelago that is located in the northern part of Jakarta, the capital of Indonesia. This area has complex geomorphology, consisting of various ecosystems, such as coral reefs, mangroves, seagrass beds and supplies a wide range of fisheries products to the greater Jakarta area. Kepulauan Seribu has high fisheries resources, with total catch landing from marine fishing activity in 2013 was 1555 ton [13]. These fisheries resources require a good fisheries management so that it can be used sustainably. Information about the characteristics of fish habitat in Kepulauan Seribu waters can support the implementation of sustainable fisheries management.

The aim of this study was to analyze the habitat characteristic of four fish species in the Kepulauan Seribu waters by evaluating the relationship between CPUE and various oceanographic parameters that influence it. The results of this study were expected to provide information about the distribution and the habitat of these fish. Such information can be used to map the potential fishing ground, to increase fishing benefit and to support better fisheries management.

2. Methods

2.1. Study area

The study area encompassed the fishing ground of lift net fisheries which was located in the waters of Kepulauan Seribu with Lancang Island as their fishing base. Geographically, the area was bounded by $106^{o}19$'E to $106^{o}51$'E and $5^{o}33$'S to $6^{o}5$'S, including some small islands in this region (figure 1).

2.2. Data Acquisition

The data that was used in this analysis were obtained from the lift net fisheries in Lancang Island. These fisheries were artisanal fisheries and did a one-day fishing trip that operates at night and took the advantage of light to attract and to concentrate fishes. The data used in this analysis were fishing location data, catches landing data and some oceanographic parameter data.

The fishing location data was derived from GPS recorded data. The data were collected from 11 fishing vessels in Lancang Island from 2014 to 2015. The catch landing data was derived from four dominant species that were caught by lift net, namely anchovies (*Stolephorus* sp.), squid (*Loligo* sp.), scads (*Selaroides leptolepis*) and sardines (*Sardinella fimbriata*). The catch landing data during 2014–2015 was collected from an officer who was appointed by Ministry of Marine and Fisheries of Indonesia and was in the form of monthly catch landing by lift net fisheries in Lancang Island.

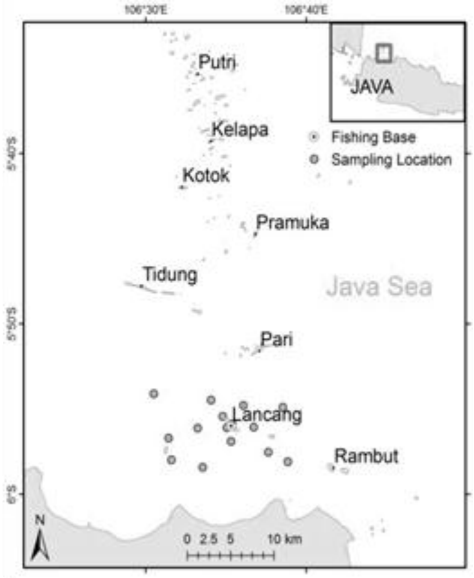

Figure 1. Map of the study area. The sampling site distributed around Lancang Island, which was the fishing base of lift net fisheries in Kepulauan Seribu Waters.

The oceanographic parameter data that were used in this study were sea surface temperature (SST), chlorophyll-a concentration, sea surface height (SSH), currents, bathymetry and total suspended solids (TSS). These data were used as an explanatory variable in the analysis of habitat characteristic. These oceanography parameters were satellite-derived data and downloaded from 2014 to 2015 (table 1). To validate these oceanographic data, the in situ data were collected in June 2015 and taken from several locations around the waters of Lancang Island (figure 1). The in situ data, namely SST and TSS, were collected using multiparameter water quality checker.

Table 1. Oceanographic parameter data which were used in analysis of habitat characteristics.

Variable	Unit	Source	Resolution
Sea Surface Temperature (SST)	Celcius ($^{\circ}$C)	INDESO	0.02 degree
Chlorophyll-*a* concentration	mg·m^{-3}	INDESO	0.02 degree
Sea Surface Height (SSH)	m	INDESO	1/12 degree
Currents	m·s^{-1}	INDESO	1/12 degree
Bathymetry	m	ETOPO1	1 Arc minute
Total Suspended Solid	mg·L^{-1}	Landsat 8	30 meters

2.3. Data Analysis

2.3.1. Catch per Unit Effort (CPUE). CPUE data was calculated from monthly catch landing data which was divided by the monthly fishing effort. Fishing effort data was present in the monthly fishing trip form and was obtained from direct interviews with several captains of lift net fisheries in Lancang Island.

2.3.2. Estimation of Total Suspended Solid (TSS). TSS data was extracted from Landsat 8 images that were downloaded from the ESPA website (http://espa.cr.usgs.gov/). The downloaded Landsat 8 image was 24 images in total and in the form of Surface Reflectance (SR) which had been corrected atmospherically. Correction of Landsat 8 image to SR was done using Landsat Surface Reflectance Code (LaSRC) algorithm [14, 15]. Landsat 8 SR data was then calibrated by dividing all digital number values by 10,000. The calibrated SR data was then masked using CFMask algorithm to remove clouds and land in an image.

TSS in mg·L^{-1} was derived from Landsat 8 surface reflectance data using algorithm in [16],

$$TSS = A*\exp^{(S*R(0)\ \text{red band})}$$

where A = 8.1429, S = 23.704 and R(0) is surface reflectance.

2.3.3. Accuracy Assessment. The accuracy assessment was used to evaluate the accuracy of estimated TSS data from Landsat 8 image and downloaded SST data from INDESO. This analysis evaluated the accuracy of these data based on the coefficient of determination (R^2) value, Mean Absolute Percentage Error (MAPE) and Root Mean Squared Error (RMSE). This analysis used the in situ data as the comparison data.

2.3.4. Analysis of Habitat Characteristic using Generalized Additive Models (GAMs). This analysis used fishing locations data, CPUE and some oceanographic parameters data. This analysis was done to understand the preferred habitat of four fish species which were investigated in this study. CPUE and some oceanography parameters were transformed in term of logarithm natural to normalize the distribution of the data. Generalized Additive Models (GAMs) with Gaussian distribution and identity link function was used to evaluate the relationship between CPUE with some oceanography parameters. GAMs approach non-linear and non-parametric technique for regression modeling and its main advantage compared to the traditional regression methods is its ability to analyze the relationship between the variable response and the explanatory variables, which are highly non-linear and non-

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monotonic [10, 12]. GAMs was constructed using the gam function within the mgcv R package (R x64 3.3.2).

The forward stepwise and shrinkage approaches were used in the final selection model. This approach allowed us to avoid collinearity among the explanatory variables. The model selection was based on the lowest value of Akaike Information Creation (AIC), the level of Deviance Explained (DE) and inspection of residual plots (i.e., QQ plots). The degree of smoothing for each explanatory variables was chosen based on the Restricted Maximum Likelihood (REML). The likelihood methods are less prone to local minimal than other smoothness selection criteria (i.e., Generalized Cross Validation, Un-biased Risk Estimator, etc.), allowed us to avoid over-fitting and to simplify the interpretation result [17]. Followed the method in [9], the thin plate spline smoother regression was applied to the models, with the maximum degree of smoothing freedom (k) for the main effects was limited to 5. The explanatory variables with significant levels of < 0.05 were kept for the final models.

3. Results

Figure 2 showed the increasing of anchovy CPUE from year to year, in contrast with sardine, scad and squid CPUE which were decreased in 2014. Seasonally, sardine and squid had high CPUE in west monsoon (December–February), while anchovy and scad were relatively stable. The catch of the lift net fisheries in Kepulauan Seribu waters was dominated by anchovies, followed by sardines and scad and squid. IT showed that the Kepulauan Seribus waters were the preferred habitat of anchovy.

3.1. Accuracy Assessment

The results of accuracy assessment in figure 3 showed that in situ SST and downloaded SST from INDESO had a good relationship (R^2 = 0.9028). The difference in the value of in situ SST and downloaded SST from INDESO can be categorized as small (RMSE = 0.86 $^{\circ}$C; MAPE = 2.93 %). For TSS parameters, the results of this analysis showed that in situ TSS and estimated TSS from Landsat 8 image have a low relation (R^2 = 0.3384). The error of TSS data can be categorized as small (RMSE = 6.1 mg·L^{-1}; MAPE = 19.65 %). The estimated TSS from Landsat 8 image had a lower value than in situ TSS. However, the results of the comparison showed that *in situ* TSS and estimated TSS from Landsat 8 had the same pattern. From this result, it could be concluded that the INDESO SST data and the estimated TSS data from Landsat 8 could be used in this study.

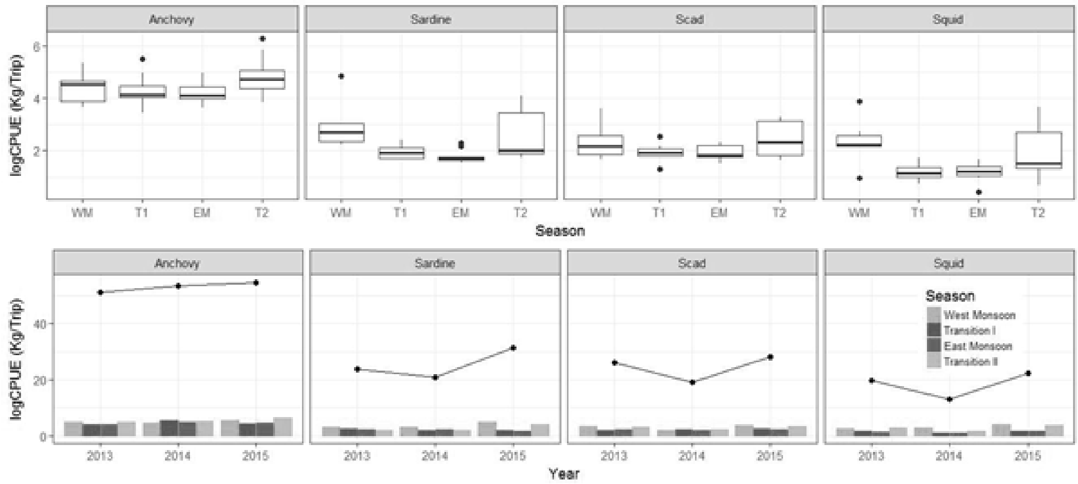

Figure 2. Profile of CPUE data of lift net fisheries in Kepulauan Seribus waters. WM: West Monsoon (Dec–Feb); T1: Transition 1 (Mar–May); EM: East Monsoon (Jun–Aug); T2: Transtition 2 (Sep–Nov).

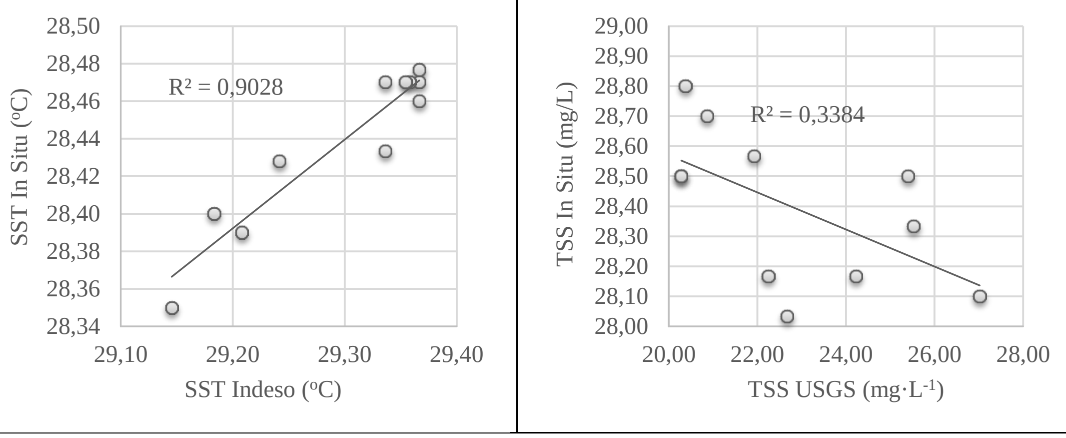

Figure 3. The linear relationship between sea surface temperature (SST) data from INDESO and total suspended solid (TSS) data from Landsat 8 with in-situ data in Kepulauan Seribu waters.

3.2. Analysis of Habitat Characteristic

Table 2 showed the seasonal average of oceanographic parameters on fishing locations in the Kepulauan Seribu waters. Oceanographic conditions on fishing locations were changed every season. The highest average of total suspended solids (TSS) occurred in the transitional II. Sea surface temperature (SST) relatively had a stable condition. The average of current speed and sea surface height (SSH) in each season were fluctuated and tended to had the same pattern, where when the current speed increased, the SSH also increased.

The result of habitat characteristic analysis with GAMs showed that the habitat characteristic was varied by the species (figure 4–7). Analysis of habitat characteristics was done after considering all the statistical measurements and the diagnostic plot results. Deviance explained in the final model varied between 77.3 % (anchovy) to 92.9 % (sardine). The natural logarithm of sea surface temperature (sst), the natural logarithm of chlorophyll-*a* concentration (chl), the natural logarithm of total suspended solid (tss), the natural logarithm of sea surface height (ssh) and the natural logarithm of current were found significant ($p < 0.05$) for all target species of lift net fisheries (table 3).

Table 2. Profile of oceanographic parameters on fishing location of lift net fisheries in Kepulauan Seribu waters.

Season	TSS ($mg \cdot L^{-1}$)	SSH (m)	Chlorophyll-a ($mg \cdot m^{-3}$)	SST (^{o}C)	Current ($m \cdot s^{-1}$)
West Monsoon	20.99	0.61	3.22	28.87	0.06
Transition I	19.06	0.68	2.05	29.17	0.16
East Monsoon	23.65	0.72	1.76	29.27	0.17
Transition II	58.00	0.65	5.47	29.08	0.14
Average	32.56	0.68	2.98	29.16	0.15

Table 3. Final GAMs model from each target species of lift net fisheries in Kepulauan Seribu waters. CPUE and all explanatory variable were transformed in terms of the natural logarithm. DE: Deviance Explained.

CPUE	Final Model	DE
Anchovy	s(ssh) + s(chl) + s(sst) + s(current) + s(tss)	77.3%
Squid	s(ssh) + s(sst) + s(current) + s(tss)	87.7%
Sardine	s(ssh) + s(chl) + s(sst) + s(current) + s(tss)	92.9%
Scad	s(ssh) + s(chl) + s(sst) + s(current) + s(tss)	87.6%

Table 4 showed that TSS and SSH parameters had high F value on each species. From this result, it could be concluded that these parameters gave a high influence on the value of CPUE. TSS parameters could affect the fish distribution and SSH parameters could affect the fishing activities. These oceanographic parameters could directly affect the value of CPUE of lift net fisheries in the Kepulauan Seribu waters.

Table 4. The F value from the result of GAMs analysis. The F value indicated the degree of influence of the oceanographic parameter on the CPUE of fish species in Kepulauan Seribu waters.

Species	F Value				
	s(ssh)	s(chl)	s(sst)	s(current)	s(tss)
Anchovy	36.097	20.669	21.437	9.372	75.29
Squid	53.287	7.288	11.399	18.578	137.306
Sardine	78.741	0.955	39.148	8.5	102.289
Scad	75.772	5.141	6.041	8.654	44.509

The plot of the best smoothing showed a higher probability of finding high CPUE of anchovy and squid at SST from 28 to 29 °C and sardine and scad from 29 to 30°C (figure 4–7). In chlorophyll-a concentration parameter, the plot of the best fitting smooth showed high CPUE of sardine and scad could be found at 0.61–1.1 $mg \cdot m^{-3}$ and at 0.41–1 $mg \cdot m^{-3}$ for anchovy. Their preferred habitat corresponded to Eutrophic and upper Mesotrophic waters (Oligotrophic waters: < 0.084 $mg \cdot m^{-3}$; Lower Mesotrophic waters: 0.084–0.359 $mg \cdot m^{-3}$; Upper Mesotrophic waters: 0.36–0.793 $mg \cdot m^{-3}$; Eutrophic waters: > 0.793 $mg \cdot m^{-3}$) [18].

The probability of finding higher CPUE, according to GAMs plot in sea surface height (ssh) parameter, for anchovy and squid were at 0.74–0.8 m and for sardine and scad were at 0.6–0.65 m. Total suspended solid is an important parameter for environmental monitoring in the coastal area. The plot of the best fitting smooth showed high CPUE of all target species found at TSS concentration of 54–67 mg·L^{-1} and at current velocity of 0.12–0.22 m·s^{-1} (figure 4–7).

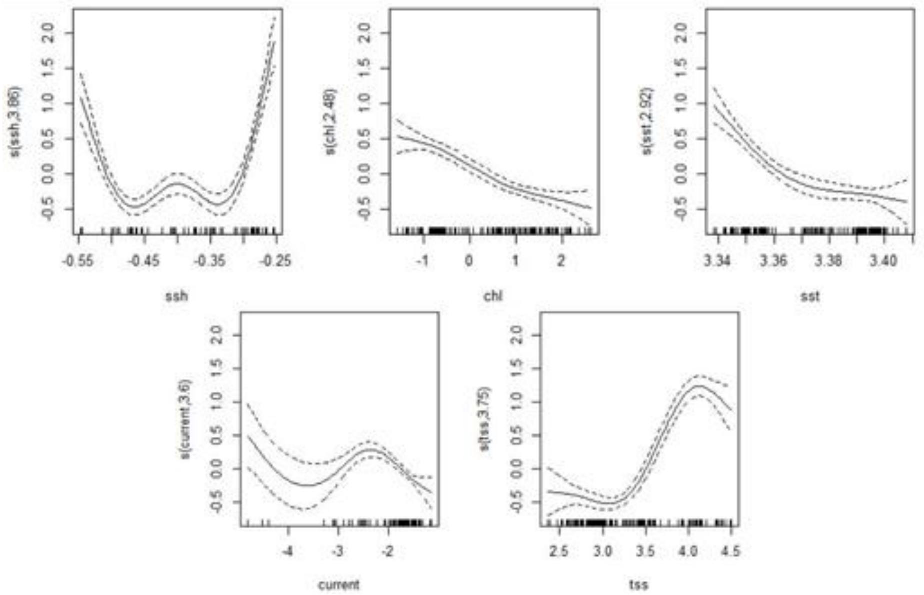

Figure 4. Plots of the best fitting smooth in GAMs analysis for anchovy.

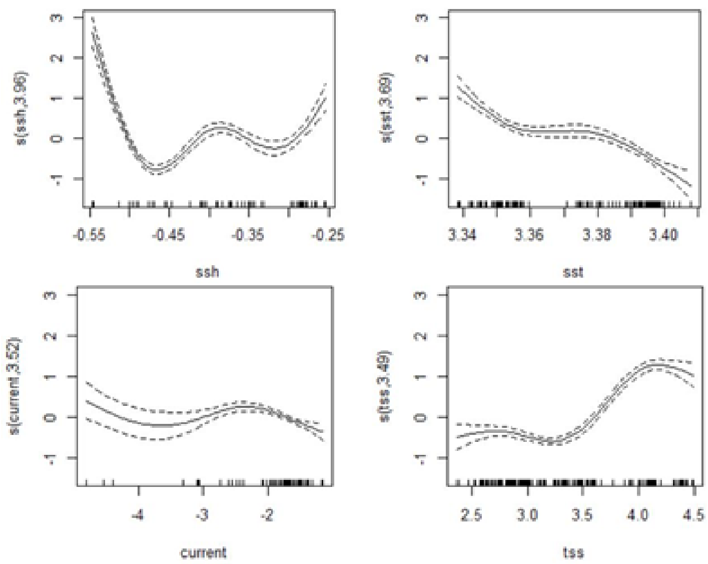

Figure 5. Plots of the best fitting smooth in GAMs analysis for squid.

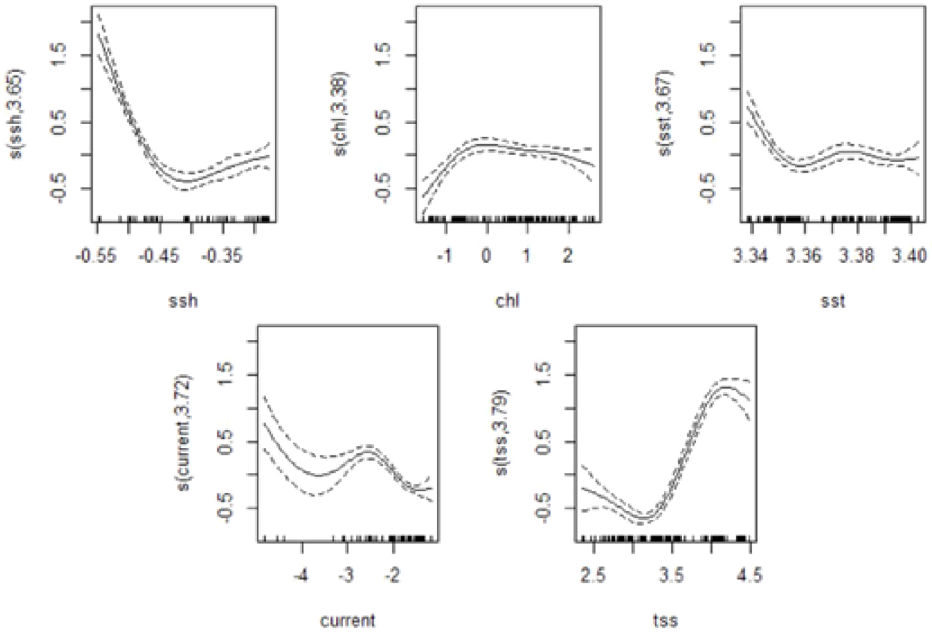

Figure 6. Plots of the best fitting smooth in GAMs analysis for sardine.

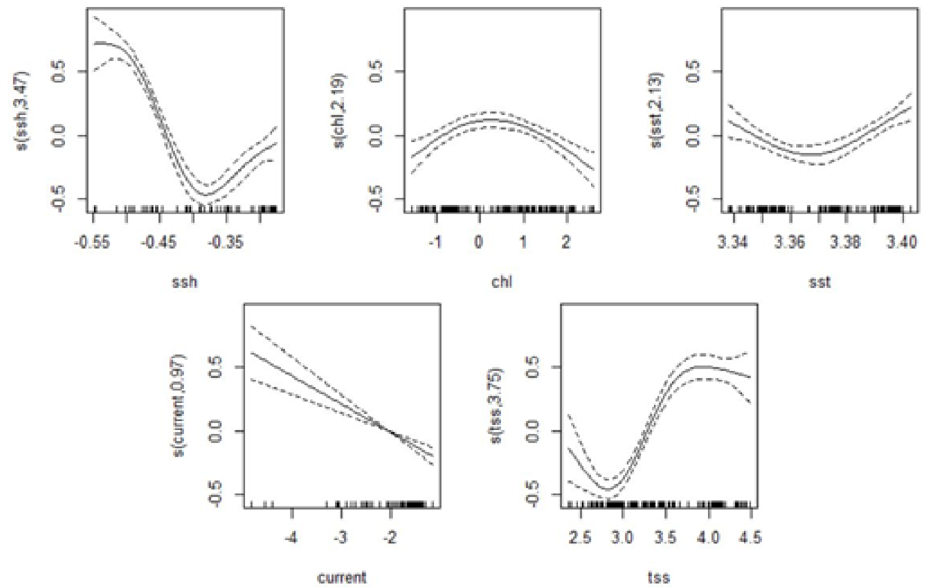

Figure 7. Plots of the best fitting smooth in GAMs analysis for scad.

4. Discussion

Using Generalized Additive Models (GAMS) for habitat characteristic analysis, CPUE data, fishing location data and some oceanographic parameters data were integrated. The result of this analysis showed that each target species had different preferred oceanographic characteristics and distributed on varying range of oceanographic parameters. Sea surface height (SSH) and total suspended solids (TSS) have a high influence on the value of CPUE. SSH could affect fishing activities and TSS could affect the distribution of fish.

In nature, organisms distributed uniformly or randomly but converged in an area with particular characteristics [19]. On fisheries, the spread of efforts and catches had some relationships with the distribution of targeted species that were affected by their preferred habitat characteristic (i.e. the availability of coral reefs and seagrass) and oceanographic parameters (i.e. temperature, chlorophyll concentration and currents) [20]. Based on the results of habitat characteristics analysis, several oceanographic parameters influence the CPUE. These oceanographic parameters were sea surface temperature, chlorophyll-*a* concentration, sea surface height, current and total suspended solids.

Temperature is one of the factors that significantly affect the distribution of fish [21]. Changes in the temperature of the waters can affect the metabolism of the fish, the growth of gonads and the predation and can indirectly affect the level of reproduction, survival and the catches of fish [22]. The concentration of chlorophyll-*a* in the waters can be used as an indicator of the productivity of a marine environment and may affect the distribution of certain fish. The concentration of chlorophyll-*a* widely had been used to identify the level of primary productivity [23] and at a level above 0.2 $mg \cdot m^{-3}$, the concentration of chlorophyll-*a* can support some fishing activities in an area [24].

Sea surface height (SSH) and currents can be analyzed to identify the mass movement of water, heat and nutrient flow, which can affect the productivity of marine environment [25]. Also, SSH can also be used to predict the other oceanography features, such as fronts, eddies and convergences [26].

Sediment, an essential element in aquatic ecosystems cycle, is in the form of suspended particles, transported and deposited by water [27]. The increase of sediment concentrations often caused by anthropogenic activities, such as mining, agriculture and urban development. The increasing of precipitation, the increasing of temperatures and the melting of ice which were associated with climate change also indirectly affects the increased of sediment concentration [28]. The increasing of total suspended solids (TSS) concentration in the waters can affect spawning, migration, movement pattern, development and growth of the aquatic organisms [7]. In fish, the effect of TSS was depended on several factors, such as the species, the temperature at exposure time the type of sediment [29], the frequency and the concentration of TSS [28].

Bathymetry parameter was not found significant to CPUE value. This was probably due to the CPUE data which was obtained from small pelagic species, where their habitat was located on the sea surface. However, bathymetry data which showed the depth profile of an area is considered as one of the factors that may affect the distribution of certain fish species [9]. Depth has a significant relationship with various important environmental parameters, such as temperature, oxygen and nutrient concentration, light intensity and primary productivity of a waters.

By utilizing the CPUE relationship with some oceanographic parameters as input in spatial analysis assessments, allowed us to generate information of the potential fishing ground and the distribution of fisheries resources. With that information, stakeholders could define a better fisheries management policy to ensure the sustainability of a fishery resource.

5. Conclusion

Each observed fish species had different habitat characteristics. Sea surface temperature, chlorophyll-*a* concentration, total suspended solids, sea surface height, and current were found to significantly affect the CPUE of lift net fisheries in Kepulauan Seribu waters. Total suspended solid and sea surface height gave a high influence on CPUE value. Total suspended solid affected the distribution of fish and sea surface height affected the fishing activities. All species were found to be highly distributed in the TSS range of 49.40–67 $mg \cdot L^{-1}$. The catch of anchovy and squid were high when the SSH value was in the range of 0.74–0.78 m, while the catch of scad and sardine were high when SSH value was in the range 0.60–0.64 m. High CPUE values occurred in certain water conditions.

The use of GPS data and catch data at the fishing locations needs to be improved so that the results of this analysis can be more reliable. For further research, by using the result of this study, mapping the potential fishing ground area can be done. Improving the fishery management in Kepulauan Seribu can be done by enforcing the logbook policies to be more optimal and better information on fisheries activity can be obtained.

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