Environmental Factors Affecting Miter Squid *Uroteuthis chinensis* Catch from Cast Net Fishery in Indonesia Fisheries Management Area 711

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ABSTRACT

The miter squid *Uroteuthis chinensis* is the main species targeted by cast net vessels operating in Indonesia Fisheries Management Area (IFMA) 711. A study of the factors that influence miter squid catch was conducted in this area to improve the efficiency of fishing efforts and support the management of the squid fishery. This study uses a generalized additive model (GAM) to describe the effect of marine environmental and vessel-related factors on miter squid catches within IFMA 711. Catch data were obtained from 59 cast net vessels after 113 completed fishing trips. In addition, oceanographic data from satellite images, including sea surface temperature, chlorophyll *a*, wind speed, and current velocity, were analyzed to determine how they affected the catch. The results showed an overall catch of miter squid from the cast net vessels was 1,151.21 t for 2020. The GAM produced the best-fit model with 141.72 as the Akaike Information Criterion (AIC) score, explaining 51.50 % of the total variance. Four variables had strong impact on the catch: vessel size, chlorophyll *a*, sea surface temperature, and wind speed. This study emphasizes the importance of understanding the factors that may lead to increased squid catches. As a result, for effective fishing efforts, water conditions and the monsoon cycle must be considered. These findings demonstrate that the factors affecting the miter squid catch from a marine environmental perspective can be reasonably predicted and provide valuable information for the sustainable use of squid when combined with an understanding of their life cycle.

Keywords: Cast net, Generalized additive model, Marine environment, Miter squid, Satellite image

INTRODUCTION

Squid is a fisheries resource with substantial economic value. It is an increasingly significant commodity in the global seafood trade, valued at nearly USD 8.2 billion, with Asian countries being the contributors of about sixty percent of world squid landings in 2019 (SFP, 2022). Based on data retrieved from 252 countries or territories over 20 years (2000-2019), Indonesia, along with North Korea, South Korea, China, Thailand, Vietnam, and India, have established a strong squid trading and distribution system in Asia in terms of both monetary value and volume (Alvarez *et al*., 2022). In addition, Suryanto *et al*. (2021) reported that Indonesian squid exports totaled 66,450 t in 2020, with 10.7 % contributed from Indonesia Fisheries Management Area (IFMA) 711.

IFMA 711 covers the Karimata Strait, the Natuna Sea, and the South China Sea. In these waters, Suryanto *et al*. (2021) found that the cast net was the dominant fishing gear for catching miter squid, *Uroteuthis* (*Photololigo*) *chinensis*. This species is mostly landed in the port of Tanjung Balai Karimun (Ghofar, 1999). In addition, the miter squid is one of the main fishery species, and is relatively abundant in almost all western Indonesian marine waters (Jereb *et al*., 2010).

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Studies have shown that the marine environment affects the squid catch. For example, squid catches were higher in fishing grounds with a high concentration of chlorophyll *a*, and vice versa (Jebri *et al*., 2022). In addition, Robin and Denis (1999) reported that annual trends in squid landings and temperature were related. The squid migrate over short distances in response to local water temperatures (Wang *et al*., 2021). Moreover, sea surface temperature, current speed, and winds influence the seasonal phytoplankton concentration, causing variation in squid catches (Jebri *et al*., 2022). The habitat and abundance of squid were found to be closely related to oceanographic parameters, which change both at spatial and time scales (Alabia *et al*., 2015; Yu *et al*., 2020). Areas with high squid abundance lead to high catches. Other than oceanographic parameters, many factors can influence squid catches, such as the efficiency of the fishing gear used, the fishing technique applied, the number of vessels operating, and the duration of at-sea fishing operations.

Several previous studies related to the fish and marine environment in IFMA-711 focused on spatiotemporal distribution and biological characteristics of pelagic fish, growth aspects of *Uroteuthis*, and the distribution, abundance, and harvest of squid (Suwarso *et al*., 2019; Fauziyah *et al*., 2020). However, the response of miter squid catches to changes in marine environmental variables has yet to be studied quantitatively. An analysis in a dynamic model that can predict future yields would be very useful for stakeholders (Ghofar, 2005).

The generalized additive model (GAM) (Hastie and Tibshirani, 1986) is a modification of the generalized linear model, in which the response variable depends linearly on the smooth function of the explanatory variable, with an emphasis on generalizations about this smooth function. It is frequently used to investigate specific environmental connections because it can analyze the nonlinear relationship between the dependent and independent variables (Mugo *et al*., 2010). Several studies have been conducted using GAM to forecast the effects of the marine environment on squid catch in various seas, including the Arabian Sea, the Pearl River Estuary, and the Northwest Pacific Ocean (Tian *et al*., 2009; Solanki *et al*., 2017; Wang *et al*., 2021).

This study describes the effect of oceanographic and vessel-related factors on squid catches. This includes a general analysis of miter squid catches from cast net vessels operating in IFMA 711 in 2020. Monthly profiles of oceanographic parameters in IFMA 711 were derived from remote sensing satellite data. Factors that have significant impact on miter squid catches were identified using GAM.

MATERIALS AND METHODS

The research site was IFMA 711, which covers approximately 656,880 km^2 with geographical coordinates of 4.13° S to 7.79° N and 102.29-111.05° E (Figure 1). Data preparation and processing were conducted at Universitas Diponegoro's Ocean and Coastal Remote Sensing Laboratory in Semarang, Indonesia.

Miter squid landing data and fishery-related variables

The miter squid catch data from cast net vessels were obtained from landing records at Tanjung Balai Kairmun Port in 2020. This study used the yield from 59 cast net vessels fishing in waters more than 19.3 km from the shoreline as primary data, representing a total of 113 fishing trips. The year of data collection (2020) was selected as the most recent year with complete catch data available. In addition, this study considered fishery-related variables such as vessel trip duration, size, and engine power, which could potentially affect fluctuations in miter squid catches.

Marine environmental data

In this study, satellite-derived wind speed, sea surface temperature, chlorophyll *a* concentration, and current velocity, as well as vessel trip duration, size, and engine power were used as explanatory variables to indicate the variability of miter squid catch. The characteristics of the oceanographic data are summarized in Table 1. ArcGIS v10.8 was used to process all satellite image data.

Table 1. Characteristics of oceanographic data used for study of miter squid catch.

Data type	Description	Data source
Sea surface temperature (SST)	SST in °C, at the spatial resolution of 4 km	http://oceancolor.gsfc.nasa.gov
Sea surface chlorophyll *a* (CHL)	CHL in mg·m^{-3}, at the spatial resolution of 4 km	http://oceancolor.gsfc.nasa.gov
Wind speed (WS)	The neutral-stability wind 10 m above the water surface in m·s^{-1}, at the spatial resolution of 0.25° in longitude and latitude	https://resources.marine.copernicus.eu DOI: 10.48670/moi-00181
Current velocity (CV)	Global total surface and 15 m current from altimetric geostrophic current and modeled Ekman current reprocessing in m·s^{-1}, at the spatial resolution of 0.25° in longitude and latitude	https://resources.marine.copernicus.eu DOI: 10.48670/moi-00049

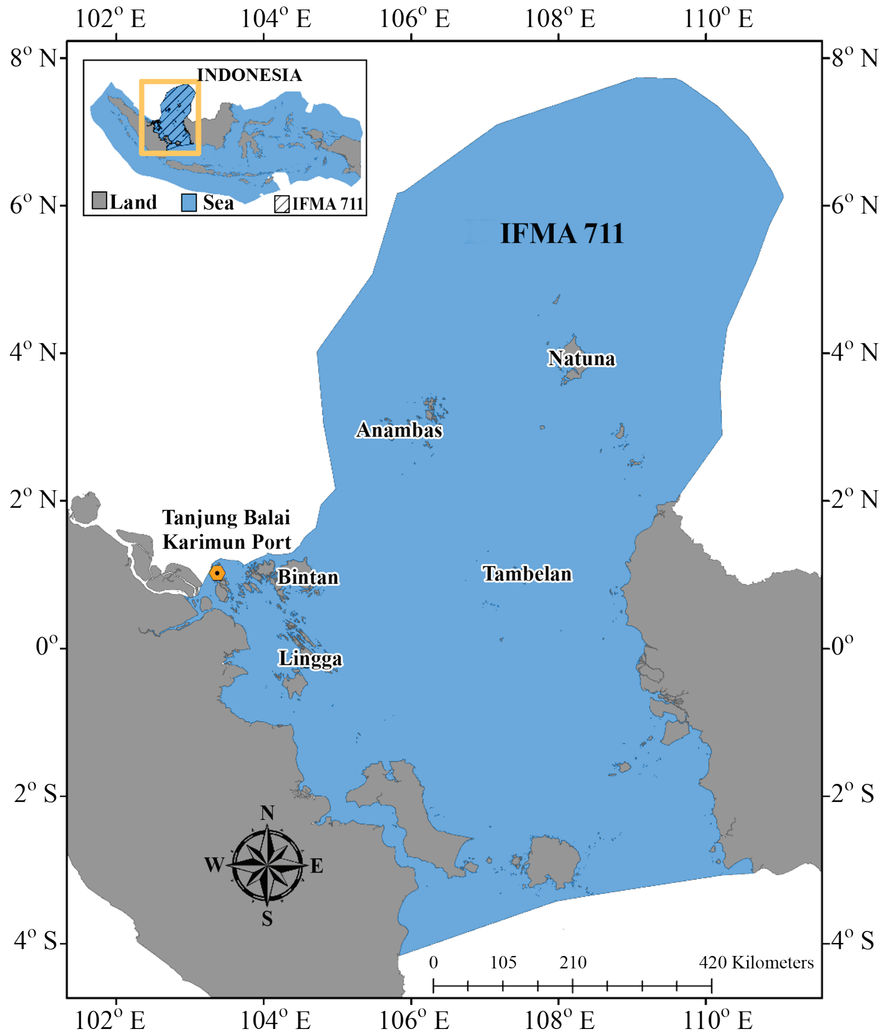

Figure 1. Map of Indonesia Fisheries Management Area IFMA 711, the focus of the study.

Basic assumptions for analysis

IFMA 711 is a fishing ground for cast net vessels targeting miter squid. Cast net vessels with known vessel size (VZ) and engine power (EP) are used to catch squid in one fishing operation as long as the trip duration (TD) produces satisfactory yield of miter squid catch. The amount of yield corresponds with a change in environmental factors among fishing trips.

If the vessel starts fishing at month "sm" and landing at month "lm" then the mean of monthly marine environmental variable that affects the catch (ME) was calculated as follows (Equation 1):

$$ME_k = \frac{1}{(lm\text{-}sm)+1} \times \sum_{i=sm}^{lm} k_i \qquad (1)$$

where k_i is the marine environmental data (SST, CHL, WS, or CV) in the month i.

Statistical analysis

The GAM was employed to evaluate the relationship of changes in environmental variables to miter squid catches. The asymmetric frequency distribution of the catch data was normalized using logarithmic adaptation to apply the identity link function with the Gaussian distribution in GAM (Hoyle *et al*., 2014). The catch was considered a response variable. The explanatory variables consisted of trip duration, size of the vessel, engine power of the vessel, chlorophyll *a* concentration, sea surface temperature, wind speed, and current velocity. The GAM basic model was formulated as follows (Equation 2):

$$\ln(Catch) = s(TD)+s(VZ)+s(EP)+s(SST)+s(WS)+s(CV)+s(CHL) \qquad (2)$$

where ln (Catch) is the natural logarithm of the catch data, s denotes the smoothing splines function. The effect of trip duration is denoted by s(TD). Furthermore, s(VZ) is the effect of the size of the vessel. s(EP) is the effect of the engine power of the vessel. In addition, s(SST), s(WS), s(CV), s(CHL) are the effects of mean sea surface temperature, wind speed, current velocity, and chlorophyll *a* concentration during a fishing trip, respectively.

A stepwise forward strategy was applied to choose factors that substantially impact the model for determining the particular expression of GAM. The selection of the best fit model results in GAM analysis using Akaike Information Criterion (AIC) for each GAM model formed. R software v4.0.0 was used to process the GAM analysis. The GAM was built in R language using the mgcv package, a mixed GAM computation vehicle with automatic smoothness estimation (Wood, 2017).

AIC is a method for evaluating the forecast's performance based on the relationship between maximum likelihood and Kullback-Leibler divergence (information theory). AIC is a great tool for selecting models since it provides an approximation of the relative quality of all the models that are available for a particular data set. According to Burnham and Anderson (2002), Each candidate model is subjected to AIC, and the model with the lowest score is chosen in application. Out of all the potential models taken into consideration, this one is thought to be the one that is most similar to the unknowable reality that produces the data.

RESULTS AND DISCUSSION

Catch of miter squid

The cast net vessels that landed squid in the port of Tanjung Balai Karimun during our sampling period varied in size from 36 to 142 GT, with engine power in the range of 40-400 HP (Table 2). These vessels caught squid within IFMA 711 in 2020, producing 1,151.21 t and with a mean trip duration of 81±22 days. Similarly, Suwarso *et al*. (2019) reported that squid fishing vessels using the fishing grounds of IFMA 711 and the Java Sea had an average trip length of 82 days.

Relationship between marine environmental variables

In most Indonesian waters, oceanographic characteristics highly depend on the seasons (Wirasatriya *et al*., 2018). Figure 2 shows profiles of the monthly means of chlorophyll *a* concentration, sea surface temperature, wind speed, and current velocity in IFMA 711 during January to December,

Table 2. Summary statistics for miter squid cast net fishery in 2020 from Indonesia Fisheries Management Area IFMA 711.

Statistic	Vessel size (GT)	Engine power (HP)	Trip duration (days)	Catch (t)
Minimum	36.00	40.00	16	1.17
Maximum	142.00	400.00	129	24.00
Mean	60.51	159.43	81	10.19
SD	17.03	92.86	21.8	5.19

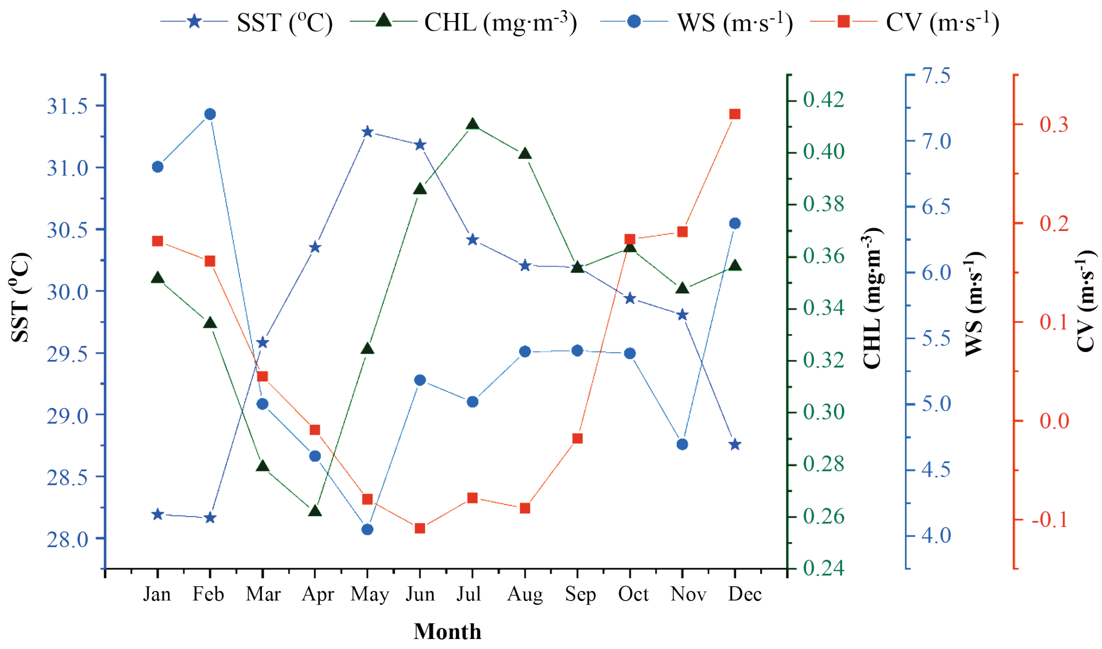

Figure 2. Year-round profiles of monthly mean sea surface temperature (SST), chlorophyll *a* concentration (CHL), wind speed (WS), and current velocity (CV) in IFMA 711 in 2020.

2020. In the west monsoon (December-February), the wind speed increased, with the highest value of 7.25 m·s^{-1} in February, while the other three variables decreased. According to Maisyarah *et al.* (2019), strong monsoon winds could lead to an escalation in Ekman transport, a great heat loss due to the beginning of the rainy season, along with evaporation and the lateral mixing of water masses, resulting in the occurrence of cooling water surface temperature. Then, in the first transitional season (March-May), sea surface temperature increased gradually. At the same time, the other three variables decreased, except for the concentration of CHL, which experienced a significant increase in May. The rise in CHL concentration continued until July, then dropped in August.

In the east monsoon (June-August), SST gradually decreased in contrast to the conditions in the previous season. Furthermore, in this season, the wind speed and current velocity variables showed opposite trends, with wind speed first increasing and later decreasing. Conversely, current velocity first declined, then later increased. Finally, in the second transitional season (September-November), the current velocity gradually rose. In contrast, the decline in SST continued. In addition, the concentration of chlorophyll-*a* fluctuated, while wind speed tended to decrease. The current velocity in April-September was negative but positive in other months. Following Shah *et al*. (2019), negative and positive values represented Ekman mass transport. Positive values indicate upward velocity, whereas negative values indicate downward velocity. Downwelling areas have higher sea surface elevation than surrounding waters. Upwelling areas, on the other hand, are distinguished by a drop in sea level, because of the relatively calm subsurface waters.

Pre-analysis selection of explanatory variables

The Pearson correlation was used to perform analysis of explanatory variables to prevent the model-fitting process from being numerically unstable or causing problems similar to overfitting. Table 3 shows two pairs of variables with strong correlation, both values greater than 0.5. These were trip duration with chlorophyll *a* and vessel size with engine power. Therefore, one of the pairs needed to be eliminated. The strong relationship between chlorophyll *a* and trip duration was probably caused by fluctuations in the abundance of squid, which under certain conditions are strongly influenced by the level of abundance of phytoplankton. Jebri *et al*. (2022) reported that annual squid abundance was positively correlated with chlorophyll *a* fluctuations in the sea. When the abundance of squid is high, there is potential for higher catch per effort, which in turn will shorten the duration of the fishing trip. The vessel will return to the port when the hold is filled. The higher the catch per effort, the shorter the duration of the fishing trip. As a result, chlorophyll *a* was kept (rather than trip duration) as a predictor variable. Vessel size was chosen over engine power for the model, considering the vessel size better reflects catch capacity of the vessel.

GAM analysis

After selecting the explanatory variables, GAM was used to fit and determine the effects of vessel size and environmental variables on miter squid catch in IFMA 711. The explanatory variables were added to the GAM, and the tests were performed to generate AIC scores (Table 4). The results show

Table 3. Correlation matrix (Pearson) of explanatory variables.

Variables	TD	VZ	EP	SST	CHL	WS	CV
Trip duration (TD)	-	-0.022	-0.058	0.169	0.718	0.406	-0.342
Vessel size (VZ)		-	0.534	0.132	-0.018	-0.135	-0.081
Engine power (EP)			-	0.092	-0.050	-0.157	-0.052
Sea surface temperature (SST)				-	0.350	-0.675	-0.429
Chlorophyll *a* (CHL)					-	0.387	-0.604
Wind speed (WS)						-	0.000
Current velocity (CV)							-

Table 4. Generalized additive models (GAM) for miter squid fishery, with Akaike Information Criterion (AIC) scores.

Model	Degree of freedom	AIC	Deviance explained
ln Catch = s(VZ)	3.00	196.29	3.87 %
ln Catch = s(VZ)+s(SST)	8.70	191.77	16.50 %
ln Catch = s(VZ)+s(SST)+s(WS)	18.64	147.28	45.80 %
ln Catch = s(VZ)+s(SST)+s(WS)+s(CV)	15.28	145.85	50.90 %
ln Catch = s(VZ)+s(SST)+s(WS)+s(CV)+s(CHL)	14.37	141.72	51.50 %

Note: Vessel size (VZ); Sea surface temperature (SST); Wind speed (WS); Current velocity (CV); Chlorophyll *a* (CHL) that as the number of variables increases, the AIC score decreases. The final model shows 141.72 as the AIC score, explaining 51.50 % of the total variance. Furthermore, the addition of the current velocity variable to the model only slightly changes the AIC value (less than 2), indicating that the effect of this variable is minimal. In other words, four variables have a substantial impact on the catch: vessel size, chlorophyll *a*, sea surface temperature, and wind speed.

Response plots from the best-fitting GAM with both oceanographic and vessel-related variables are shown in Figure 3. Response plots show a dome-shaped relationship between vessel size and the number of miter squid caught, with higher values occurring in the 60-105 GT range (Figure 3a). For vessels smaller than 60 GT or greater than 105 GT, the catch tended to decrease. The confidence interval widens for larger vessels. The narrow confidence limits denote high relevance distribution scales, whereas the broad confidence limits denote low relevance distribution scales. The SST plot forms a wave, with a downward trend in the range 29-29.5 °C and greater than 30.5 °C, and an upward trend in the range 29.5-30.5 °C, with confidence intervals that tend to widen at temperatures greater or less than 30.5 °C (Figure 3b). In addition, with higher wind speed, the catch tended to decline (Figure 3c). The influence of current velocity and sea surface chlorophyll *a* on the catch are depicted by negative linear trends (Figure 3d and Figure 3e). The confidence intervals for wind speed, current velocity, and CHL widened at greater or less than 4.8 $m \cdot s^{-1}$, -0.1 $m \cdot s^{-1}$, and 0.33 $mg \cdot m^{-3}$, respectively.

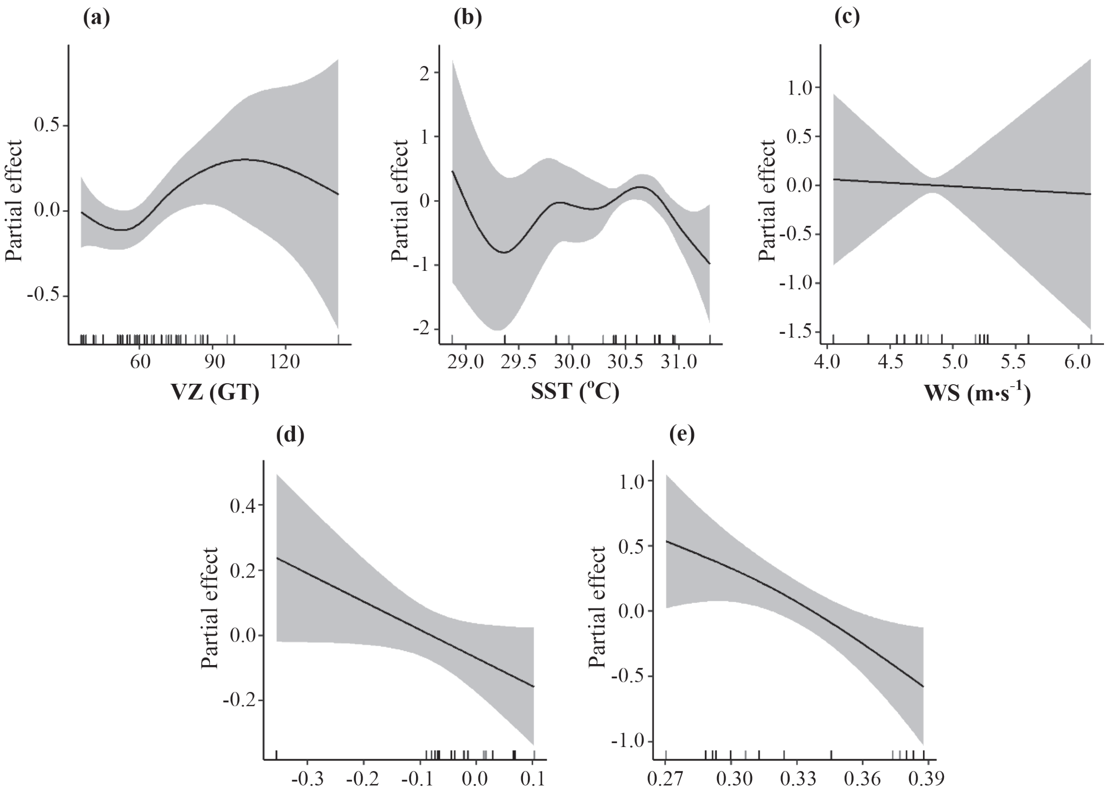

Figure 3. Generalized additive model (GAM) analysis of the effects of trip duration, vessel size, and environmental variables on miter squid catch in IFMA 711: (a) vessel size (VZ); (b) sea surface temperature (SST); (c) wind speed (WS); (d) current velocity (CV); and (e) sea surface chlorophyll *a* (CHL). The shaded areas represent 95 % confidence intervals. The x-axis rug plots show the relative frequency of data points.

Larger vessels, in general, have the potential to catch more fish. According to the analysis, vessels larger than 105 GT departed for fishing grounds in May and gradually returned to ports until August. Based on the oceanographic conditions, that fishing month (August) did not have a high potential for squid abundance. This could have resulted in decreased catches for vessels larger than 105 GT (Figure 3a).

Changes in SST can create mass movements of water. There is a temperature difference between the layer that is penetrated by sunlight and the layer below that is not penetrated during the transition from the rainy season to the dry season, when previously high rainfall decreases, accompanied by high intensity of sunlight hitting the sea surface. This temperature difference encourages the movement of cold, nutrient-rich water masses from the lower layer to the sea surface. These nutrient-rich waters drive the growth of plankton and microscopic algae in these waters. The high fertility of these waters creates a feeding ground for small fish, a source of food for squid (Cahya *et al*., 2016). In this study, the catch increased for surface temperatures in the range of 29.5-30.5 °C, indicating that the water conditions were favorable for abundant food, forming a feeding ground for schooling and foraging miter squid (Figure 3c). Water conditions above 30.5 °C, on the other hand, may result in low catches, which may be indicative of miter squid spawning at nearshore locations (less than 12 miles), which were not part of the fishing ground used by cast net vessels in this study. During the squid life cycle, rising sea temperatures stimulate migration to spawning areas (Chemshirova *et al*., 2021), whereas at temperatures below 29.5 °C, it occurs during the west monsoon with strong wind conditions (Figure 2). Because of the dangerous conditions, fishermen usually flee to the nearest island and cease fishing operations. This is consistent with the GAM analysis results, which show that higher wind speeds reduce catches (Figure 3c). Strong ocean currents are another impediment to squid fishing, as cast net fishing techniques require relatively calm currents to function. As a result, the catch decreases with rising current velocity (Figure 3d).

As illustrated in Figure 2, favorable conditions for fishing miter squid occurred in March, October, and November. In other words, the peak of the miter squid catch in 2020 was in the first and second transitional seasons. This finding is similar to the results of a study by Suwarso *et al*. (2019). Wang *et al*. (2021) reported that the miter squid was mostly found in waters with temperatures ranging from 22 to 29 °C. In addition, Jereb *et al*. (2010) found that miter squid spawning occurs all year, with spring and autumn being the peak times (February-May and August-November).

Increasing chlorophyll *a* concentrations were found to be associated with lower catches (Figure 3e). This is most likely related to the food source and trophic level of the squid. When chlorophyll *a* levels are high in the food chain, phytoplankton (as a producer) increases, which encourages an increase in the number of primary consumers, followed by an increase in the number of secondary consumers, including squid. This does not occur simultaneously, but rather with a time lag between the increase of phytoplankton and the increase in secondary consumers. Thus, a decrease in chlorophyll *a* can indicate an increase in the number of first consumers, which is a source of squid feed. The relationship between chlorophyll *a* concentration and squid abundance is not always ecologically causal (Jebri *et al*., 2022).

The Convention on Biological Diversity has promoted the ecosystem approach by emphasizing resource management and promoting a balance between human needs and biodiversity. The ecosystem approach is a strategy for integrated management of land, water, and living resources that promotes equitable conservation and sustainable use. Thus, using the ecosystem approach will aid in achieving a balance of three objectives: conservation, sustainable use, and the fair and equitable sharing of benefits resulting from the use of genetic resources (SCBD, 2004). The findings of this study, which are related to the ecosystem approach, provide an overview of favorable oceanographic conditions in the utilization of squid resources in IFMA 711. Knowing the appropriate temperature characteristics, the dynamics of chlorophyll *a* abundance, and seasonal cycles of currents and winds can support the sustainable use of squid resources. It is also critical to consider the capacity of fishing vessels as well as natural conditions that are compatible with fishing techniques. Understanding the relationship between physical and biological processes, as well as the transfer of organic matter produced by marine food webs, involves a variety of interactions. This interplay could be related to sunlight's role as the primary energy source for phytoplankton productivity and predator-prey dynamics. The biophysical processes that support survival of organisms in the sea, when combined, form the foundation for assessing the health of ecosystems that are useful in the conservation and sustainable use of squid resources. A few useful generalizations are required for ecosystem-based squid management. On a spatial and temporal scale, this includes information on population dynamics, migration patterns, spawning, nursery, and feeding grounds.

CONCLUSION

The GAM described the effects of oceanographic and vessel-related factors on miter squid catch variation in IFMA 711. GAM analysis showed four variables that have substantial impact on the catch: vessel size, chlorophyll *a*, sea surface temperature, and wind speed. Larger vessel sizes do not always result in high catches if operated in unfavorable monsoons. The catch increased in the SST range of 29.5-30.5 °C. In addition, the waters with high chlorophyll *a* require further processing via the food web to become potential squid fishing grounds. More long-term annual data will be needed in future studies to improve our understanding of marine environmental factors that affect the catch. The results of this study need to be combined with information on population dynamics, migration patterns, spawning, nursery, and feeding grounds to be effectively applied in the ecosystem-based management of squid.

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