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Relationship between Abundance of Sardines and Oceanographic Conditions in Tonkin Gulf, Vietnam

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Abstract

Sardines are key species, which contributes about 25% total biomass of small pelagic fishes, recognized as highly commercial importance in Tonkin Gulf. This study applied general additive models (GAMs) to explore the relationship between abundance of sardines and four dynamic environmental factors (temperature, surface height anomaly, chlorophyll a, current) and a static variable 'depth' in Tonkin Gulf. Data on abundance of sardines were collected during three acoustic surveys in 2012 and 2017, incorporated with satellite derived environmental data sets. Results indicated that abundance of sardines quite related to several key environmental factors (temperature, chlorophyll a, current); and also associated with bathymetry. GAM models were able to explain about 52.5-77.9% for the distribution of sardines in Tonkin Gulf.

Keywords: Sardines; Tonkin Gulf; Acoustic surveys; Oceanographic; Remote-sensing

Introduction

Sardine is small pelagic fishes, which widely distributed in the Gulf of Tonkin. It is considered as the highly economically important species in the area. Presently, sardines contribute about 25% of the total biomass of small pelagic fishes in the Tonkin Gulf.

The distribution of small pelagic species are quite sensitive to variation of environmental conditions [1]. It was showed that the abundance of these species has strongly correlated to the sea surface temperature, such as, herring in the North Sea [2]; anchovy in the coast of Chile [3]. Maravelias indicated that there was a strong relation between abundance of herring and the oceanographic condition as well as plankton density in the northern part of North Sea [4]. Safruddin et al. showed that the concentration of anchovy in Bone Gulf, Indonesia corresponded well with sea surface temperature of 29.5-30.5oC, and chlorophyll a of 0.5-1.0 mg/m-^{3} [5]. Sardine is normally distributed in optimal thermal ranges, i.e., Spanish sardine was highly concentrated in the upwelling foci to avoid the warm waters during the summer [6].

Tonkin Gulf is considered as a "semi-closed" ecosystem, placed in the sub-tropical region. In this area, the oceanographic conditions are quite heterogeneous, which strongly impact of monsoon season [7,8]. In Tonkin Gulf, it was showed that there were existing relationships between the abundance of small pelagic fishes and variation of environmental conditions, such as, temperature, salinity and other oceanographic structures [7,9]. It is indicated that high catch per unit area (kg/) of small pelagic fishes was found in the range of surface temperature from 26.0 to 29.0oC; surface salinity from 33.0 to 33.5 ppt [7]. It was also showed that the abundance of small pelagic fishes were likely associated with depth strata [9]. However, there is lack of specific information on the impacts of these environmental factors to the abundance of sardines. It is likely that the distribution of sardines is highly related to the oceanographic conditions, such as, temperature, salinity, current, chlorophyll a, etc. Therefore, it is very interesting to examine the relationship between oceanographic conditions and abundance of sardines in Tonkin Gulf.

Recently, data on abundance of sardines are available from comprehensive acoustic surveys in the Tonkin Gulf. In this study, we try to explore the relationships between the abundance of sardines and various environmental variables collected during the acoustic surveys in Tonkin Gulf. The objectives were seeking for the models that could be used to predict the abundance of sardines from oceanographic variables. With these purposes, we use the satellite derived data, which are easy to obtain continuously from remote-sensing images. This is considered much better solution than the in-situ environmental measurements data, required scientific survey cruises which is always faced to the constrains of time and budgetary [10]. Information on the relationship between abundance of sardines and environmental variables could be quite valuable to develop the fishing ground forecast models for sardines in the Tonkin Gulf.

Materials and Methods

Acoustic surveys

The survey area in this study is the western part of Tonkin Gulf, which is restricted from the coastline to the delimitation border between Viet Nam and China [11]. During period of 2012-2017, three acoustic surveys were conducted by the Research Institute for Marine Fisheries, Viet Nam to assess the abundance of small pelagic fishes in Tonkin Gulf. The first two surveys were carried out in the Southwest monsoon (May 2012) and the Northeast monsoon (October 2012) [12]. The third survey was conducted during the Southwest monsoon (Jun 2017). The acoustic track was designed following the 'zig-zag' method (Figure 1). Total length of the acoustic tracks were about 760-780 nautical miles [12]. The 'Degree of Coverage' for survey cruises was about 5.5-6.4, which could be considered as an appropriate and sufficient sampling intensity [13,14].

The acoustic data was collected continuously with a split-beam echo sounder SIMRAD EK60 on board of the research vessel M.V.SEAFDEC2, at 38 kHz, 120 kHz and 200 kHz. To ensure the accuracy of the acoustic data, the EK60 system was well-calibrated before each survey cruise

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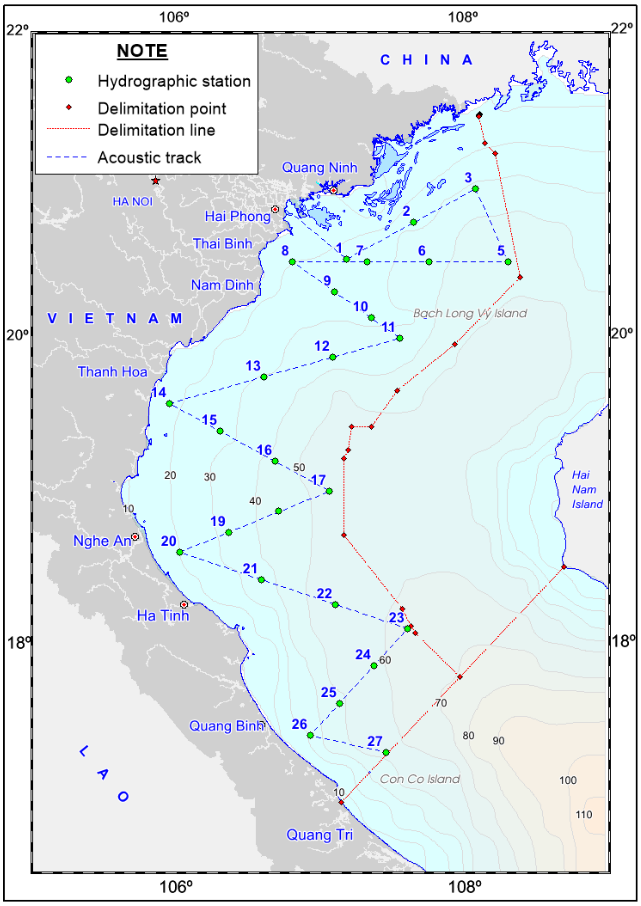


Figure 1: Study area, design of the acoustic tracks and hydrographic station during acoustic surveys (May 2012, October 2012 and June 2017) in Tonkin Gulf, Viet Nam.

[15-18]. The sailing speed was served at about 8-10 knots depending on the weather condition. All the measured echograms are recorded and stored properly for further post-processing.

During the survey, experimental fishing operations were frequently conducted using bottom trawl and mid-water trawl at the fixed stations along acoustic tracks. The bottom trawl or mid-water trawl shooting was implemented to sample on big school of fishes. All catches were identified into species, then sampled for biological analysis.

The integrated echogram was analyzed using the Large Scale Survey System (LSSS) software [19]. The relative abundance of sardines was identified as the nautical area scattering coefficient (NASC, with unit in m^2/nmi^2) or so-called the 'sA'. The sA of sardines was quantified into elementary sampling distance unit (ESDU) of 1 nautical mile (1 nmi=1.852 km). To avoid noises from the vessel and the seabed, it was eliminated the echo from 0.5 m below the transducers and 0.5 m above the bottom. The sA values of sardines for every nautical mile incorporated with position (longitude and latitude) were extracted for further analysis.

Remote-sensing data

During the surveys, a data set of satellite derived oceanographic conditions, including sea surface temperature (SST), chlorophyll a concentration (CHR), sea surface height anomaly (SSH) and absolute geographic current (VEL) was also obtained from the "Collecte Localisation Satellites - CLS" by the "Themis Viewer" (Table 1). The data was quantified into 0.1-degree resolution and extracted for further analysis. Due to the insufficient coverage of daily data, the mean composite spans were taken for whole survey period.

Fitting models

We used four dynamic environmental variables, including SST, SSH, CHR, VEL which were obtained from satellite derived data sets. It was showed that these satellite derived hydrographic parameters were corresponded with abundance of the small pelagic species [20,21]. One static variable 'depth' was also selected. These key environmental factors were acting as independent variables, which could characterize the oceanographic conditions in the Tonkin Gulf. Nautical area scattering coefficient (sA) of sardines from acoustic surveys was acting as dependent variable. The spatial scale of environmental variables and relative abundance of sardines 'sA' were quantified into resolution of 0.1 degree.

We used the Generalized Additive Models (GAMs) to discover the relationship between the relative abundance of sardines (sA – m^2/nmi^2) and environmental variables. Tweedie distribution or so-called "Poisson Gamma Distribution" was used since the sardine sA was quite right skewed [10,22,23]. The GAMs used a log-link function to establish between the mean and a smooth function of candidate explanatory variables [22,24].

The potential models were formulated from combinations of five candidate explanatory environmental variables (SST, SSH, CHR, VEL, DEP), including single, two, three, four and five variables models. Total 31 potential GAM's models were formulated for each survey cruise. GAMs were fitted using 'mgcv' library in R [25,24].

A model selection procedure was operated to identify the 'best fit' model among the potential GAM's models. First, we selected the models with explanatory variables significant at $P<0.05$. Then, the one with the lowest value of Akaike Information Criteria (AIC) was selected as the 'best fit' model [26]. In case, there were several models with the same AIC, the model with higher deviance explained was selected as the best model. The "smoother" log link function was used to perform the mean and range of confidence for the relationship of sardines sA and explanatory variables.

Results

Oceanographic conditions

The sea surface temperature was quite high during surveys in the Southwest monsoon (May 2012 and June 2017), while it was lower in

Parameters	Variable	Units	Source
Relative abundance			
NASC of sardines	sA	m^2/nmi^2	Hydro-acoustic surveys
Dynamic variables (remote-sensing)			
Sea Surface Temperature	SST	°C	AVHRR SST
Chlorophyll a	CHR	mg/m^3	SeaWiFS
Sea Surface Height Anomaly	SSH	cm	Satellite derived modelling
Absolute Geographic Current	VEL	m/s	
Static variable			
Depth (static variable)	DEP	m	Hydro-acoustic surveys

Table 1: Variables used in the GAM's models.

the Northeast monsoon survey (October 2012). During surveys in the May 2012, October 2012 and June 2017, average sea surface temperature was about 29.8 ± 0.01°C, 28.7 ± 0.01°C; and 29.9 ± 0.01°C, respectively; average chlorophyll a concentration was 0.2 ± 0.01 mg/m³; 0.3 ± 0.01 mg/m³; and 1.4 ± 0.1 mg/m³, respectively. Other environmental variables were showed in Table 2.

In the Northeast monsoon (October 2012), there was existing strong current, transferred cold water masses from the North to the South along the west coast of Tonkin Gulf. This might create a cool water area along the coast, which quite separated from other water masses in the Tonkin Gulf. In the Southwest monsoon (June 2017), the typical seasonal current from the South to the North was prevailed, which might drive 'up-welling' areas along the west coast of Tonkin Gulf. Therefore, it might create high concentrated areas of chlorophyll a. In May 2012, the weather was changed from Northeast to the Southwest monsoon, so the currents were quite mixed. There were existing two cold water masses, which was quite separated from other water masses of the Tonkin Gulf. Detail key oceanographic features in Tonkin Gulf were showed in Figure 2.

Relative abundance of sardines (sA)

The relative abundance of sardines was performed as the nautical area scattering coefficient (sA-m²/nmi²). The relative abundance of sardines in the Tonkin Gulf was seasonally fluctuated. The average sA of sardines during the Southwest monsoon surveys were lower than those during the Northeast monsoon survey. It was about 45.3 ± 3.2 m²/nmi² in May 2012; 53.1 ± 7.0 m²/nmi² in October 2012; and 45.7 ± 4.3 m²/nmi² in June 2017. The sA values of sardines in all surveys were strongly right-skewed (Table 2).

It was showed that the relative abundance of sardines was likely influenced in the ranges of environmental factors. During the survey in May 2012, sardine's abundance was highest within the SST range 29.1-29.7°C, with a peak at 29.1°C. The highest abundance of sardines was at chlorophyll a concentration of 0.3 mg/m³. The depth range of high abundance was 40-50 m. In October 2012, the high abundance of sardines was at SST range 28.6-28.7 °C; chlorophyll a concentration of 0.3-0.5 mg/m³; and depth range 30-40 m. In June 2017, the high abundance of sardines was at SST range 29.6-30°C; chlorophyll a concentration range 0.4-0.5 mg/m³; and depth range 20-30 m (Figure 3).

Sardines were quite widely distributed in the Tonkin Gulf. The abundance of sardines was highly heterogeneous in the survey area. Areas of high abundance were found around the North and the West of Bach Long Vy island and offshore area of Nghe An (Figure 2). It was showed that sardines were mainly distributed in the area, where depth ranged from 20 to 50 m. In May 2012, high abundance of sardines was found in the North of Bach Long Vy and the offshore area of Nghe An, at depth range 40-50 m. In October 2012, the sardines were concentrated at the West of Bach Long Vy, at depth range 20-40 m. In June 2017, the West and the North of Bach Long Vy were presence of high abundance areas, at depth range 20-40 m. Almost high abundance of sardines were found at the transition areas between water masses, which formulated by oceanographic features (Figure 2).

GAM models fitting

GAMs results showed that the final model for surveys was well fitted, using Tweedie distribution at γ=1.82-1.9. The explained deviance of final models ranged from 52.5 to77.9%, and was highest in October 2012 model. Almost all explanatory variables in the final models were highly significant with $p<0.01$. All the final models for the survey cruises included a dynamic variable 'sea surface temperature' and a static variable 'depth'. It indicated interesting relation of sardine's abundance with sea surface temperature and depth (Table 3).

May 2012 model:

$$\rho=s(SST,1.00)+s(SSH,2.79)+ s(VEL,2.41)+s(DEP,7.79)+3.68$$

The final model was included three dynamic variables (sea surface temperature, sea surface height anomaly, absolute geographic current) and static variable 'depth', with explained deviance 55.3% (Table 3). The abundance of sardines was decreased with increase of sea surface temperature. It was slightly decreased with increase of sea surface height anomaly range less than -2 cm; then increased with SSH. The abundance of sardines tended to increase with the absolute geographic current range less than 0.15 m/s; then decreased with increase of current. With increase of depth, the sA was increased within range 10 – 40 m, 54 – 68 m and >90 m; with highest value at depth of 40 m; it decreased within range 40 – 54 m and 68 – 90 m (Figure 4).

October 2012 model:

$$\rho=s(SST,6.70)+s(CHR,6.01)+s(DEP,5.97)+3.19$$

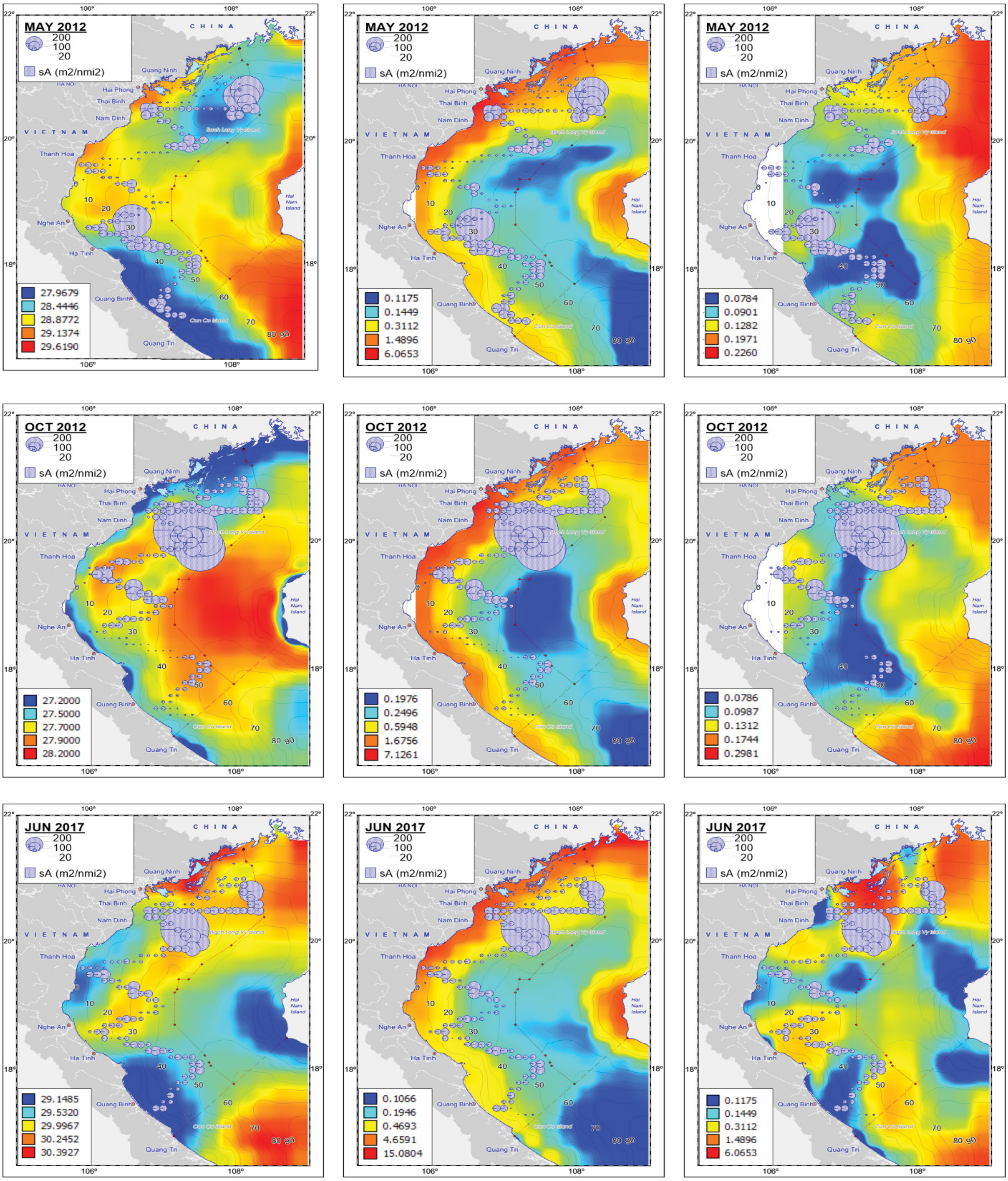
The final model was consisted of two dynamic variables (sea surface temperature, chlorophyll a) and static variable 'depth'. This model performed the best 'fitted' with the explained deviance 77.9%. All explanatory variables in the final model were highly significant, with $p<0.001$ (Table 3). It was decrease with increase of sea surface temperature in range <28.5, 28.7 – 28.8; and increase in range 28.5 – 28.7 °C and > 28.8 °C. The sA was increase with very low chlorophyll a concentration, with peak at 0.3 mg/m³; then it tended to decrease with increase of chlorophyll a concentration. The sA was quite high in shallow waters, less than 30 m; it then decreased with increase of depth within range 30 – 60 m; then it was slightly increased with depth (Figure 4).

June 2017 model:

$$\rho=s(SST,6.22)+s(CHR,1.00)+ s(VEL,5.86)+s(DEP,1.00)+3.64$$

Relative abundance of sardines and oceanographic condition	May 2012			October 2012			June 2017		
	Mean	SE	Skew	Mean	SE	Skew	Mean	SE	Skew
Relative abundance of sardines									
sA (m²/nmi²)	45.3	3.2	8.7	53.1	7.0	13.2	45.7	4.3	16.8
Remote-sensing									
Sea Surface Temperature (°C)	29.81	0.02	0.01	28.73	0.01	-0.08	29.90	0.01	-0.70
Sea Surface Height Anomaly (cm)	-0.27	0.11	0.69	27.52	0.22	-1.13	-4.77	0.12	1.04
Chlorophyll a (mg/m³)	0.16	0.00	4.11	0.33	0.01	2.73	1.38	0.07	2.90
Absolute Geographic Current (m/s)	0.16	0.00	0.38	0.14	0.00	0.89	0.16	0.00	1.05

Table 2: Summary of relative abundance of sardines (sA – m²/nmi²) and environmental factors during the acoustic surveys in Tonkin Gulf, Viet Nam.



Sea Surface Temperature | Chlorophyll *a* | Absolute Current

Figure 2: Key oceanographic factors (sea surface temperature, chlorophyll a concentration, absolute geographic current) during acoustic surveys in Tonkin Gulf, Viet Nam.

Model	Tweedie	n	DE (%)	Estimate of smoother of GAM models					
				SST	CHR	SSH	VEL	DEP	Intercept
May 2012	1.82	105	55.3	1.00^{*}		2.79^{**}	2.41^{*}	7.79^{***}	3.68^{***}
October 2012	1.99	109	77.9	6.70^{***}	6.01^{***}			5.97^{***}	3.19^{***}
June 2017	1.99	142	52.5	6.22^{***}	1.00^{*}		5.86^{***}	1.00^{**}	3.64^{***}

DE is the explained deviance; "*", "**", "***" denoted for significance p-value < 0.05, 0.01 and 0.001 respectively

Table 3: GAM's model fitted for sardine's relative abundance (sA) and oceanographic conditions in the Tonkin Gulf, Viet Nam.

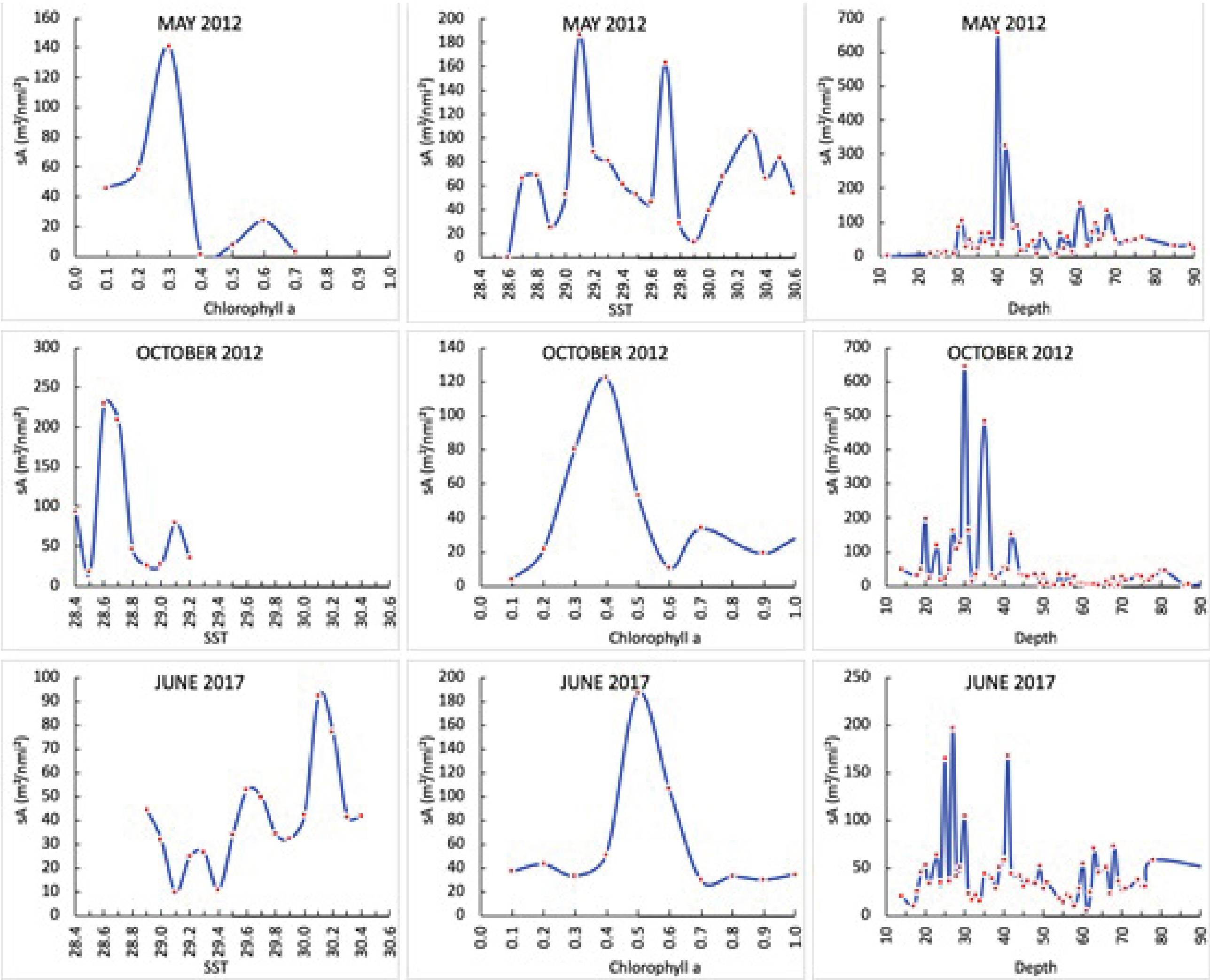


Figure 3: Relative abundance of sardines (sA – m²/nmi²) related to the range of some key environmental factors during the acoustic surveys in the Tonkin Gulf, Viet Nam.

The final model included three dynamic variables (sea surface temperature, chlorophyll a, absolute geographic current) and static depth, with the explained deviance 52.5% (Table 3). In the final model, the abundance of sardines was decrease with increase of chlorophyll a concentration and depth. With increase of sea surface temperature, it was increase in range < 29.7°C and > 29.9°C; decrease within range 29.7 – 29.9°C. With absolute geographic current, the sA was increase within range 0.13 – 0.21 cm; it was decrease in range <0.13 cm and > 0.21 cm (Figure 4).

Discussion

Exploring relationships between environmental factors and distribution of small pelagic fishes using GAMs has been applied widely, due to the good performance capacity of the models. The objective of this study was to identify the relationship between distribution of sardines and satellite derived oceanographic factors in Tonkin Gulf. Results of present study indicated that, in the GAM models, abundance of sardines was quite related with several key oceanographic factors. Similar studies also indicated that oceanographic conditions influenced on small pelagic fish abundance [4,2,21]. Variation of oceanographic conditions such as, chlorophyll a, sea surface temperature, distance to the shore, depth, etc. influence on the distribution of marine fishes, especially small pelagic fishes [1,2,4,5,20,21,27,28].

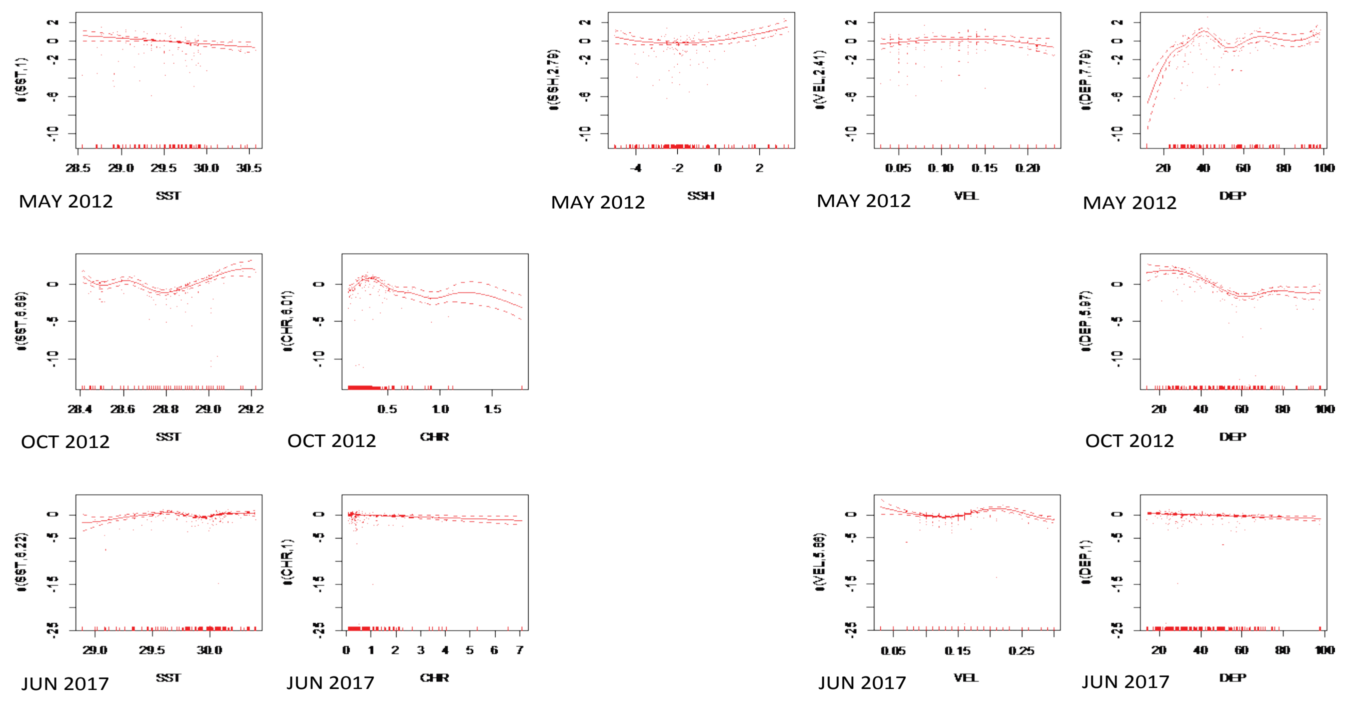


Figure 4: Smoother curves of the GAM models for sardine's relative abundance (sA) and oceanographic conditions in Tonkin Gulf, Viet Nam (solid line: mean; dash line: 95% confidence band).

In this study, GAM models indicated the interesting relationship between environmental variables and abundance of sardines in Tonkin Gulf. In the models, it was indicated that sea surface temperature, chlorophyll a concentration and absolute geographic current could consider as important dynamic explanatory variables. The results also indicated that sardines were associated with bathymetry, which related to topography and distance to the shelf break [10,29]. However, other environmental factors may influence the distribution of sardines in this areas, such as wind, salinity, lunar index [20,29], availability of food (phytoplankton and zooplankton) [30-32] and predators [20].

The present study used available data sets, including acoustic surveys for abundance of sardines, satellite derived oceanographic parameters. In acoustic surveys, fish tends to avoid the research vessel, especially in shallow waters [14,33]. The model in May 2012 indicated that abundance of sardines was decreased steeply at the shallow end of depth range. It is possible that the decrease due to vessel avoidance of fish in shallow areas. It was recognized that the distribution of fish was influenced by availability of food and other ambient environmental conditions [30-32], which could be obtained from measurements and samples. However, in-situ measurements require scientific surveys which always be constrained in time and space [10] and also costly. For quick predict of fishing ground purposes, use of satellite derived data set is a good choice. Furthermore, the GAM models in this study were able to explain about 52.5-77.9% for the distribution of sardines in Tonkin Gulf.

The results from this study indicated relationship between abundance of sardines and various oceanographic factors. Further studies are needed to understand the influenced factors on distribution of sardines, which provide knowledges for development of fishing ground forecast models. In other hand, it should also include the fish stock and fisheries assessments to understand the ecosystem functioning and fisheries in Tonkin Gulf.

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