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Effects of environmental factors on the spatio-temporal patterns of bigeyes (*Priacanthus* spp.) in the northern South China Sea

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ABSTRACT

Bigeyes (*Priacanthus* spp.; Family: Priacanthidae) are among the most significant demersal fishes in northern South China Sea (nSCS). Based on the bottom trawl data of nSCS from 2009 to 2014, this study applied the SARIMA (Seasonal Autoregressive Integrated Moving Average) model and the centre of gravity movement to analyse the spatio-temporal patterns of catch per unit effort (CPUE). Combining with the corresponding environmental factors of each trawling cruise, including bottom water temperature (BWT), bottom water salinity (BWS) and sea surface height (SSH) and their relationships with the CPUE were analysed by generalised linear model (GLM). The results indicated that, the monthly CPUE varied in half a year as a period and the peak in the first half year was obviously lower than the one in the second half year. The annual temporal trend of the centre of gravity movement was similar, which was related to the monthly variation of CPUE. Among the environmental factors, SSH had the greatest impact on CPUE, especially in October, November and December, 2009 and 2012; BWS had a significant impact on CPUE in July, August and September, 2009 and October, November and December, 2012. The spatio-temporal scale of the CPUE was mainly influenced by SSH and BWS under the effect of nSCS currents. This study presents a method for spatio-temporal variation of economic fish CPUE, integrating the centre of gravity movement and the temporal variation of the CPUE with the environmental factors, which is helpful for determining the fishery management unit and closed fishing season in the nSCS.

Keywords: Bigeye fish (*Priacanthus* spp.), Environmental factors, Generalised linear model (GLM), Northern South China Sea (nSCS), Spatio-temporal patterns

Introduction

Marine fishery resources are a prominent source of high quality animal protein for human food security in China (Jia *et al.*, 2005). Both climate change and industrial fishing have been putting enormous pressure on fish recruitment (Yu and Yu, 2009; Rooper *et al.*, 2020; Chung *et al.*, 2021), which has resulted in the drastic decline of many demersal fishes of high economic value, particularly fishes with long life-history (Zhang *et al.*, 2014). The sustainable utilisation of fishery resources has aroused wide attention from fisheries managers, stakeholders and researchers, globally. Bottom trawling (single or pair trawling) has long been viewed as a major cause for the ecological changes with overfishing (Chen, 1997). The bigeyes (*Priacanthus* spp.) form a prominent bottom trawl fishery in the northern South China Sea (nSCS) (Qiu *et al.*, 2008) and the major cohorts of north-west South China Sea shelf (Wang *et al.*, 2013). The populations of bigeye are known to be widely distributed in the middle upper or bottom layers of the sea to feed on plankton, crustacean and cephalopod larvae (Jia *et al.*, 2004; Chen *et al.*, 2005; Lu *et al.*, 2010). During 1997 to 2000, the biomass of bigeyes was 92,000 t, accounting for 3.3% of annual total fish catch in the nSCS (Jia *et al.*, 2004). It is imperative to assess the stock of bigeyes, as it is still sustaining the trawl fishery even after decades of possible overfishing.

Earlier research on bigeye fish dealt with resource distribution (Chen *et al.,* 2005; Zhang *et al.,* 2016; Cai *et al.,* 2019; Liu *et al.,* 2019; 2021), age and growth (Lester and Watson, 1985; Joung and Chen, 1992), health risks (Kuraiem *et al.,* 2016; Gu *et al.,* 2017) and population dynamics (Xiong *et al.,* 2016; Jabbar *et al.,* 2017; Cai *et al.,* 2018; Seetha *et al.,* 2018). Very few have dealt with the catch per unit effort (CPUE) for bigeyes in the region and the environmental factors conducive to the same. Fishing grounds vary with the spatio-temporal distribution patterns of the fish, which is in turn impacted by different marine environmental factors (Su *et al.,* 2002), but the roles still remain unquantified due to the ecological complexities.

Statistical models integrating environmental factors and fishery data can be scoped to infer fish spatial patterns and their interactions with the environmental factors. Generalised Linear Model (GLM), Generalised Addictive Model (GAM), Maximum Entropy Model (MAXENT) and Habitat Suitability Index model (HSI) have been applied to analyse the distribution of fish (spatial patterns and temporal variation). Among them, GLM is a vital method to study the relationships between living beings and environmental factors (Nelder and Wedderburn, 1972; Venables and Dichmont, 2004a). Generally, GLM has been used to determine the effect of environmental factors on the fishery data such as distribution of fishery resources and fishing ground, the spawning stock biomass and recruitment (Brynjarsdottir and Stefansson, 2004; Venables and Dichmont, 2004b; Zheng *et al.*, 2008; Liu and Yu, 2018; Xie *et al.*, 2020; Wu and Chen, 2020). A number of factors such as sea surface temperature (SST), sea surface height (SSH) and chlorophyll-a concentrations are considered to be important in distribution of fishes (Fan *et al.,* 2016, 2019; Liu *et al.,* 2019), but the effects of the bottom environmental factors on bigeyes still need to be analysed further. The fishery management unit by the spatio-temporal heterogeneity of bigeye resources were formulated in our previous research. The objective of the present study was to put forward a method to quantify the effects of environmental factors on structuring the spatio-temporal patterns of bigeyes.

Materials and methods

Data collection

The fishery data was derived from the Systematic Network for monitoring on fishing boats and catch in the South China Sea. A total of 6006 fishing records from both, single boat trawls and pair trawls (Table 1) were collected from the nSCS fishing area during 2009 to 2014. The fishery data set was aggregated by month and the positions of fishing nets setting were aggregated by 0.5-degree latitude and 0.5-degree longitude (the centre of grid).

Environmental factors

Data on environmental factors including BWT (bottom water temperature), BWS (bottom water salinity) and SSH (sea surface height) were collected from 01 January 2009 to 31 September 2014. BWT and BWS data with resolution of 0.08-degree latitude and 0.08-degree longitude by day was obtained from the HYCOM consortium (https://ncss.hycom.org). The SSH data was downloaded from the Copernicus Marine Service (https://marine.copernicus.eu//), with resolution of 0.5-degree latitude and 0.5-degree longitude by day.

Data collating and model building

CPUE and environmental data

Step 1: To make the catch per unit effort (CPUE) between cruises comparable, CPUE was standardised as follows:

CPUE = U / (P * T)

Step 2: The CPUE for a month was the average of the monthly CPUE. But CPUE is not continuous (there is a closed fishing season in nSCS every year), therefore the synchronised values of the environmental factors were extracted to match the CPUE.

Step 3: To resolve mismatch of resolution between the CPUE data and the environmental factors and the uneven distribution of BWT and BWS, we used Kriging interpolation (Hengl *et al.*, 2012; Wang *et al.*, 2020) to recompile values of demersal environmental factors to the same resolution with the CPUE data (Fig. 1).

SARIMA model

A seasonal autoregressive integrated moving average (SARIMA) model was used for analysing the seasonal trend of CPUE (Helfenstein, 1991; Kim *et al.*, 2015). Considering the missing CPUE data in June and July, the average of the former five months was taken as the CPUE for June and the average of the latter five months for July. The stationarity of time series was tested by ADF testing (Abyaneh *et al.,* 2016). The orders of the polynomials were determined using autocorrelation function (ACF) and partial autocorrelation function (PACF). The PACF was used to find p, while the ACF was used to find q. Seasonal polynomial orders, P and Q, were identified by examining high values at fixed intervals, which would become the orders under this circumstance. Residual

Table 1. Fishing vessel statistics for single boat and pair trawls operated in the northern South China Sea during 2009-2014

Year	Quantity of fishing vessels (ind.)	Power (kW)		Annual total output (kg)	Annual average output (kg)
		Min.	Max.		
2009	894	133.04	1261.26	61998	69.35
2010	1028	133.04	1261.26	66043	64.24
2011	569	133.04	995.19	23146	40.68
2012	350	127.16	1543.50	9965	28.47
2013	425	127.16	1543.50	16948	39.88
2014	1104	127.16	1543.50	39333	35.63 [1]

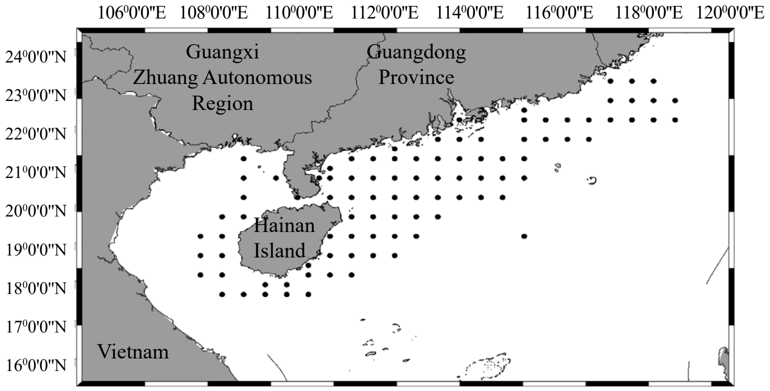


Fig. 1. Sampling sites of bigeye (*Priacanthus* spp.) in northern South China Sea during 2009-2014

tests were performed to estimate the goodness-of-fit (Ali *et al.*, 2013). The orders of the model were estimated by diagnostics test (Chen *et al.*, 2018). Then, comparing the real CPUE data and fitted values for the period 2009-2014, temporal trends were preducted for 2015-2016.

Centre of gravity movement

To analyse the centre of gravity movement with period (Liu *et al.*, 2019), the latitudes and longitudes of all fishing areas in each period were weighted with CPUE. The twelve months were divided into four periods, the first period was from January to March, the second was from April to June, the third was from July to September and the fourth was from October to December (here after referred to as P1, P2, P3 and P4). The equation on the centre of gravity in every period is as follows:

$$X = \frac{\sum_{i=1}^{n} X_i * C_i}{\sum_{i=1}^{n} C_i}$$

$$Y = \frac{\sum_{i=1}^{n} Y_i * C_i}{\sum_{i=1}^{n} C_i}$$

where X and Y are the latitude and longitude of the centre of gravity in this period; n is the total number of fishing areas; X_i, Y_i represent the latitude and longitude of the fishing area *i* and C_i is the CPUE of the fishing area *i*.

Generalised Linear Modelling

Generalised Linear Model was used to investigate the relation between spatio-temporal patterns of CPUE and the environmental factors. The factor Y= ln(CPUE + 1) was used for the model established, assuming that CPUE conforms to log-normal distribution and the constant was added to avoid zero value for the explanatory variable (Campbell, 2004; Venables and Dichmont, 2004a). The model used for GLM analyses with BWT, BWS and SSH was as follows (Zhang, 2015):

$$Y \sim \text{glm}(\text{LON} + \text{LAT} + \text{BWT} + \text{BWS} + \text{SSH}) + \varepsilon$$

where the LON and LAT are the effect of longitude and latitude respectively and the BWT, BWS and SSH represent the effect of bottom water temperature, bottom water salinity, sea surface height in sequence; ε is the error term.

The full models were built by year and month. Variable selection methods and diagnostics were using Akakita Information (AIC) value. The ideal model was formulated by backward stepwise regression (Samuel and Johnson, 1992; You and Yan, 2017). GLM were performed using the R program v .4.0.2 (R Development Core Team, 2010).

Results

Temporal variation of CPUE

The monthly CPUE cycled with half a year as a period (Fig. 2). The peak in the first half year was distinctly lower than the one in the second half year. The monthly variation of CPUE in 2009, 2010 and 2014 climbed to the maximum value of 40.5 g/ (h·kW·nets) in November 2010 and decreased to the minimum of 2.9 g (h^{-1}·kW·nets) in April 2014. The peaks in the first and second half of 2011 and 2012 were similar, but those in 2012 were higher. The CPUE in 2013 was opposite to the trend and it tended to decrease for a whole year.

The CPUE data was transformed to stationarity by taking seasonal differences. Non-seasonal differencing (d=0) and seasonal differencing (D=1) were conducted. Other orders of the polynomials could be identified by the ACF and the PACF (Fig. 3 a, b). The PACF was truncated after the lag 1 and the ACF presented an exponential

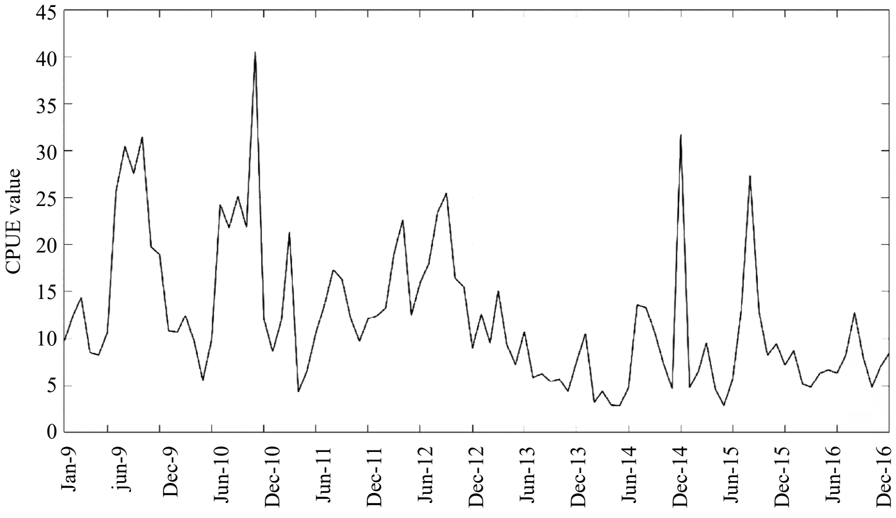


Fig. 2. Time series variation of CPUE for bigeye (*Priacanthus* spp.)

decay. The ACF showed a clear spike at lag 6. Finally, we fitted SARIMA (1, 0, 0) $(1, 1, 1)^6$ model and performed the result of diagnostics tests (Table 2). The goodness-of-fit analyses implied that the residuals of the original data have low correlation with the lagged data, indicating that the model was suitable for interpreting the original sequence and for predicting (Fig. 3 c, d). Fig. 4 shows the predicted values for 2015-2016; both the observed values and their corresponding predicted values were within the 95% confidence intervals.

Centre of gravity of CPUE

The fishing stations were mainly assembled in the range of 108°E~119.5°E, 16°N~24°N (Fig. 5). The maximum catch value occurred in 114.25°E, 20.25°N and the higher CPUE zone were distributed in the eastern and northern of Hainan waters, Beibu Gulf and south-east of Guangdong coastal waters.

A monthly variation existed in the fishing grounds' centre of gravity movement, while their distribution was rather scattered (Fig. 6). All centres of gravity were distributed between the 60 and 150 m isobaths and the annual longitude variation was about 3°. The moving trend of centre of gravity in 2009, 2010 and 2014 was similar. In P1 and P2, the centres of gravity were distributed in 113°E~114.75°E, 20°N~1.5°N. In P3, the centres of gravity moved towards Guangdong coastal waters. In P4, the centres of gravity moved south-west to eastern Hainan waters. Distance between the centres of gravity in P3 and P4 was more, but was different in 2014. In 2011 and 2012, the centres of gravity in four periods were distributed to the west of 113°E, basically off the east coast of Hainan. It is worth noting that the centres of gravity of P4 in 2012 were located around Hainan waters, which resulted in the fourth gravity situating in Hainan Island. The centres of gravity in 2013 gradually moved westward from Hainan to Guangdong coast.

Impact of environmental factors on CPUE

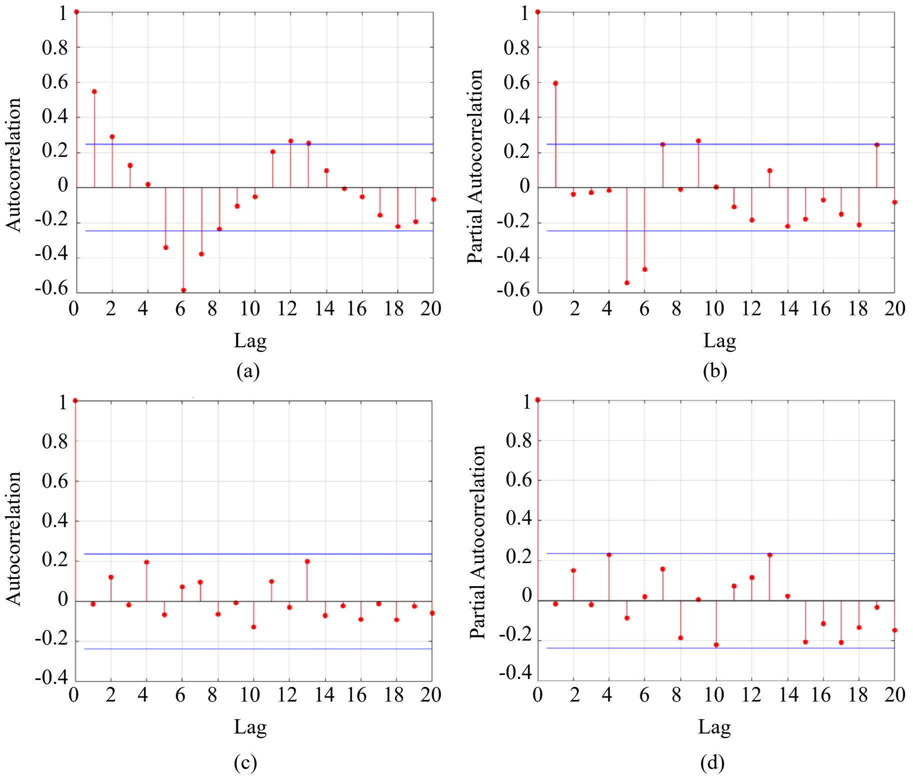
The value of the standardised regression coefficient in the best fitted models indicated the impact of the factor on CPUE (Chan *et al.*, 2020).

Table 3 shows the model fitted by year. The longitude had negative and significant impacts on CPUE in 2009, 2010 and 2014 and positive impact in 2012. The SSH had significantly negative effects on CPUE in 2009 and 2010 and BWS was positively associated with CPUE in 2010. However, BWT always had no significant impact

Table 2. The diagnostics test of the SARIMA (1, 0, 0) × $(1, 1, 1)^6$ model

	Coefficient*	Standard deviation	T value	p value
AR{1}	0.549	0.096	5.740	<0.001
SAR{6}	-0.296	0.117	-2.534	0.011
SMA{6}	-0.825	0.118	-6.980	<0.001
Variance	44.553	4.949	9.002	<0.001

**Coefficient shows the weighting of each feature and their impacts on the time series.*



(a) (b) (c) (d)

Fig. 3. ACF and PACF of the SARIMA model. (a) ACF; (b) PACF; (c) ACF of the residuals; (d) PACF of the residuals

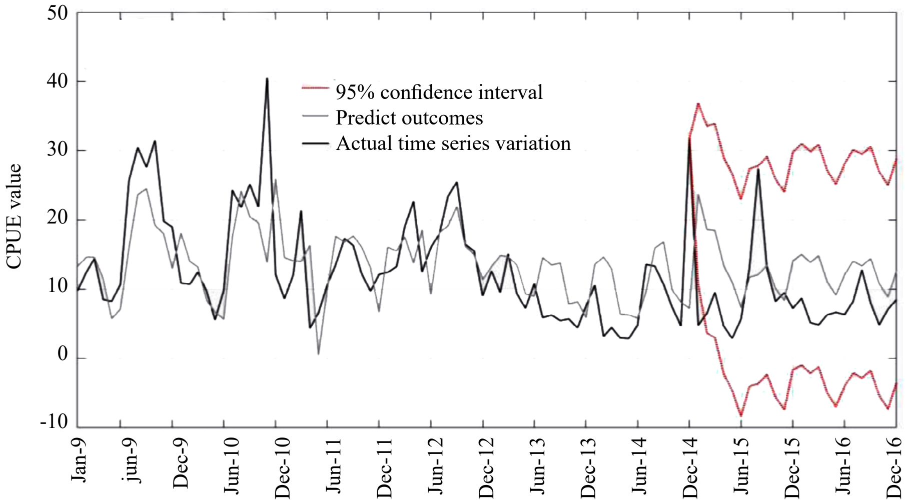


Fig. 4. Simulation of CPUE for bigeye (*Priacanthus* spp.) using SARIMA model

on CPUE.

Table 4 indicates the model fitted by month; spatial factors showed obvious impact in 2010, of which longitude was negatively correlated with CPUE in P1 and latitude was positively correlated in P2. In P3, the CPUE was positively linked with BWS in 2009 and latitude in 2013. In P4, CPUE was positively correlated with BWS in 2012, while it was negatively correlated with SSH in 2009 and 2014. The coefficients of SSH were higher than others, so SSH had the greatest impact on CPUE.

Fishing grounds were mostly distributed in the waters within the range of SSH 0.6-0.7 m in 2009 and 2010 (Fig. 7) and the optimal range of SSH for CPUE was 0.6-0.65 m. In 2010, fishing grounds were mostly located

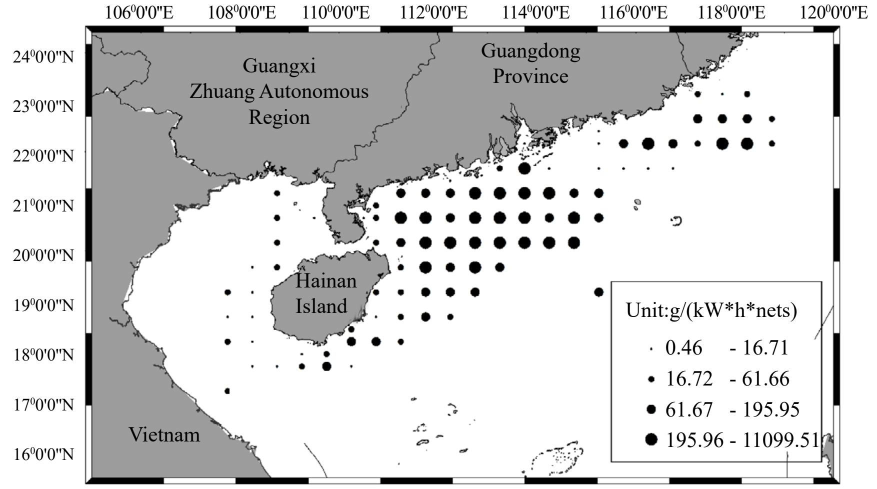
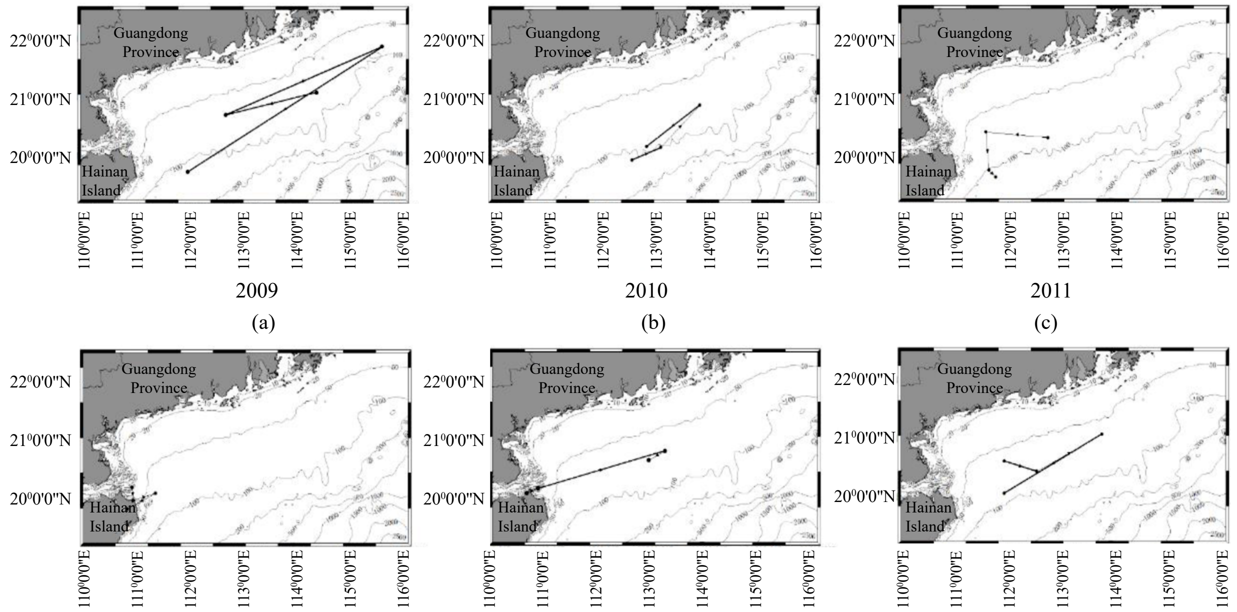


Fig. 5. CPUE distribution of bigeye (*Priacanthus* spp.) in the northern South China Sea during 2009-2014



2009 (a)
2010 (b)
2011 (c)
2012 (d)
2013 (e)
2014 (f)

Fig. 6. Movement of centres of gravity of bigeye (*Priacanthus* spp.) fishing grounds

Table 3. The GLM of CPUE by year during 2009-2014

Year	Longitude	Latitude	BWT	BWS	SSH	Intercept	Best model	AIC
2009	-0.016*			0.016	-0.539*	1.996	ln(1+CPUE)~lon+s+h	424.99
2010	-0.015*			0.017*	-0.522*	1.842	ln(1+CPUE)~lon+s+h	554.46
2011	-0.019	0.062	-0.004		-0.255	1.572	ln(1+CPUE)~lon+lat+t+h	369.05
2012	0.022*	-0.026			0.252	-1.743	ln(1+CPUE)~lon+lat+h	187.64
2013		0.046*			0.363	-0.677	ln(1+CPUE)~lat+h	280.79
2014	-0.022*				-0.384	3.332	ln(1+CPUE)~lon+h	385.29

in the area with BWS over 34 and there was little fishery data in the areas with BWS below 33.5 (Fig. 8), so the optimal range of BWS for CPUE was above 34.

Discussion

Spatio-temporal variations of CPUE

Information on interannual variation and spatial patterns of population are vital for fish population dynamics research (Dong, 2016). We found that the CPUE of bigeye in nSCS was higher in summer and lower in winter, which was consistent with the survey results by bottom trawling (Liu *et al.*, 2011) and light net falling (Liu *et al.*, 2019). The seasonal variation may be partly due to the fish spawning in spring and rapid larval growth during summer (closed fishing season). Earlier fishery survey has indicated that *Priacanthus macracanthus* was distributed evenly in SCS; the fish catch in spring was higher than in autumn (Zhang *et al.*, 2016). However, in the present study, fish catch data was derived from the trawling logbook; the bigeyes were only categorised to genus level. Longitude was a significant factor impacting CPUE of bigeye (Table 3).

This study indicates that the monthly centre of gravity movement in 2009 and 2010 were from deep waters with depths of 90 m to shallower waters about 45 m deep in nSCS. It also coincided with the highest density of bigeye fish (Jia *et al.*, 2004), but it differed from the movement of the annual centre of gravity movement (Liu *et al.*, 2019, 2021).

Studies on the spatio-temporal patterns of demersal fish help us to better understand the hot and cold spots and map out fishery management units of bigeye (Liu *et al.,* 2021). A monthly variation existed in the centre of gravity movement in the present study. The centres of gravity in P3 were situated far eastern than those in P4, with the exception of 2011, which is similar to the result of light falling-net fishing research (Liu *et al.*, 2019).

The study determined SARIMA (1, 0, 0) $(1, 1, 1)^6$ as the prediction model. The observed values had a higher magnitude of variation than the predicted values, probably related to the fluctuations of marine environments and the time-lag effects on bigeye populations.

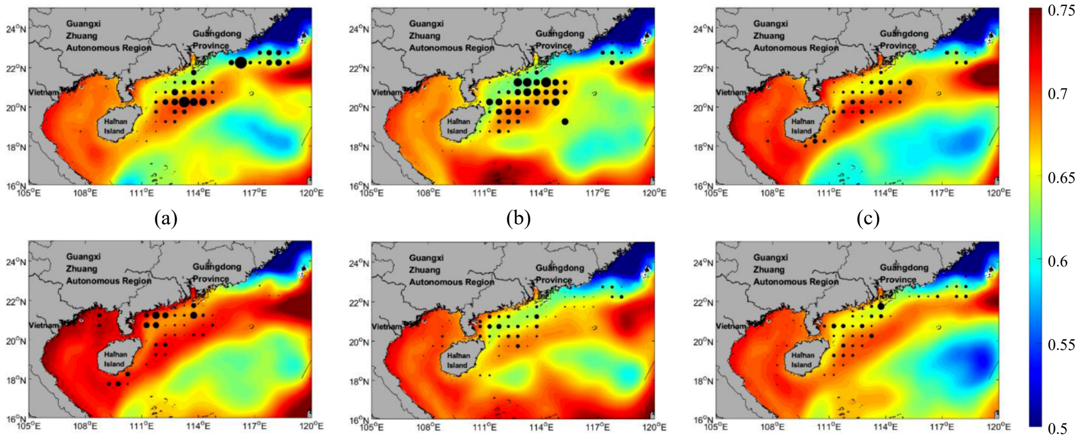
Factors influencing the CPUE

Fish populations are regulated both by their own biological characteristics and their living environment. SSH is associated with the movement of currents and has decisive effects on the fishing ground development. The CPUE of bigeye is an index on complex effects of

Table 4. The GLM of CPUE by month during 2009-2014

Period	Year	Longitude	Latitude	BWT	BWS	SSH	Intercept	Best model	AIC
1	2010	-0.046*				-0.768	6.067	ln(1+CPUE)~lon+h	140.07
2	2010	-0.063	0.129*				5.023	ln(1+CPUE)~lon+lat	64.17
3	2009	-0.049		0.011	0.031*		4.776	ln(1+CPUE)~lon+t+s	74.16
	2013	-0.033	0.086*			-0.870	1.905	ln(1+CPUE)~lon+lat+h	67.43
4	2009	-0.054*	0.075			-2.487*	6.889	ln(1+CPUE)~lon+lat+h	145.58
	2012				0.098*	-1.039*	-2.099	ln(1+CPUE)~s+h	17.65

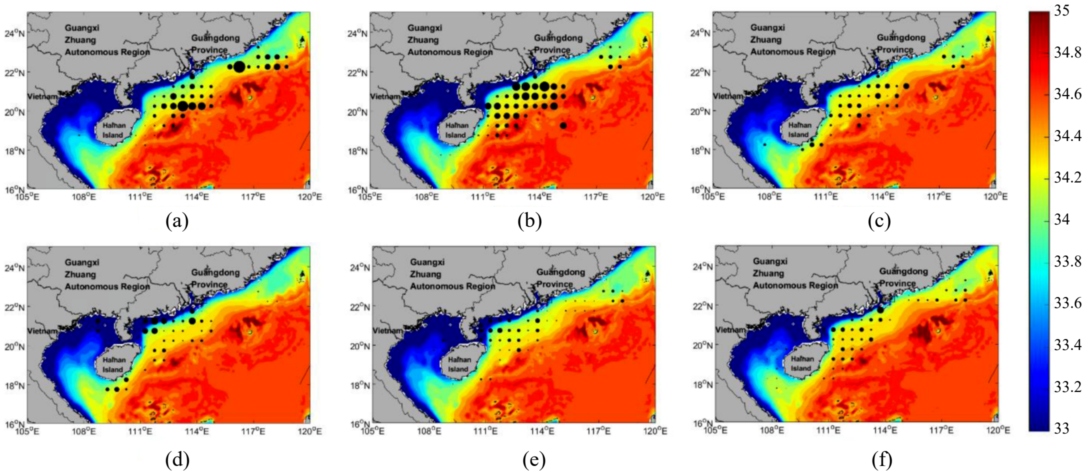
Lon: longitude, Lat: latitude. “*”: p<0.001.
Only the models with significant factors presented.



(a) (b) (c)

(d) (e) (f)

Fig. 7. The variations of SSH and CPUE for bigeye (*Priacanthus* spp.) in northern South China Sea during 2009-2014



(a) (b) (c)

(d) (e) (f)

Fig. 8. The variation of BWS and CPUE of bigeye (*Priacanthus* spp.) in northern South China Sea during 2009-2014.

the marine currents, including upwelling, downwelling and the runoff of Pearl River. Coastal upwelling in western Guangdong occurs in April to September, while Qiongdong Upwelling is driven by monsoon (Han *et al.*, 1990), usually formed during June to August. Upwelling increased the primary productivity in the meeting area of water masses in the Pearl River Estuary, offering abundant baits for fish.

The BWS was the most significant factor affecting CPUE. The monsoon drove the coastal currents and convective movement of surface water, which promoted the formation of downwelling of eastern Guangdong in December (Liu *et al.*, 2010) and high salinity water was brought to sea bottom by downwelling in winter. In summer, Qiongdong upwelling brought high salinity water to the sea surface and moved to the east coast of Guangdong. Meanwhile, BWS maintained at over 34 due to the high salinity water injected from the off-shore sea to sea bottom of western Guangdong (Li, 1990). The salinity may influence foraging, gathering and distribution of fish (Barber *et al.*, 1997; Ji *et al.*, 2015; Ma *et al.*, 2020), which thus conforms to the GLM result in this study.

The SSH was also a main factor affecting CPUE. Wind stress and Kuroshio intrusion led to seasonal variation in SSH (Xu and Oey, 2015) and have an obvious effect in autumn and winter (Liu *et al.*, 2002). SSH indirectly affects the foraging behaviour of bigeye fish. As an index of convergence and divergence of the seawater, SSH directly influences the distribution, reproduction and growth of pelagic cephalopods (Xie e*t al.*, 2020); high *Sthenoteuthis oualaniensis* CPUE in SSH of 0.6-0.75 m coincided with the results of the present study in which SSH indirectly affected the distribution of bigeye in P4.

This study also demonstrated the non-significance of BWT on the CPUE of bigeye. However, earlier research indicates that the interactions of water depth (D) and SST strongly affect CPUE in each season (Fan *et al.*, 2019). In this study, the lack of synchronisation of ecological factors such as plankton and sea currents may lead to bias. The GLM results of the present study confirm BWS and SSH as the significant factors impacting the CPUE of bigeye in the northern South China Sea.

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References

Abyaneh, H. Z., Afruzi, A., Mirzaei, M. and Bagheri, H. 2016. Forecasting the reference evapotranspiration using time series model. *J. Water Soil*, 30(1): 99-111. https://doi.org/10.22067/jsw.v30i1.38212.

Ali, M., Kim, D. R., Yunus, M. and Emch, M. 2013. Time series analysis of Cholera in Matlab, Bangladesh, during 1988-2001. *J. Health Popul. Nutr.*, 31(1): 11-19. https://doi.org/10.3329/jhpn.v31i1.14744.

Barber, W. E., Smith, R., Vallarino, M. and Meyer, R. 1997. Demersal fish assemblages of the northeastern Chukchi Sea, Alaska. *Fish. Bull.*, 95(2): 195-209.

Brynjarsdottir, J. and Stefansson, G. 2004. Analysis of cod catch data from Icelandic groundfish surveys using generalized linear models. *Fish. Res.,* 70(2-3): 195-208. https://doi.org/10.1016/j.fishres.2004.08.004.

Cai, Y. C., Huang, Z. R., Xu, Y. W., Sun, M. S., Xu, S. N., Zhang, K. and Chen, Z. Z. 2019. Probability distribution characteristics of stock density in offshore of northern South China Sea. *J. Appl. Ecol.*, 30(7): 2426-2436. https://doi.org/10.13287/j.1001-9332.201907.015.

Cai, Y. C., Xu, S. N., Chen, Z. Z., Xu, Y. W., Jiang, Y. E. and Yang, C. P. 2018. Current status of community structure and diversity of fishery resources in offshore northern South China Sea. *South China Fish. Sci.,* 14(2): 10-18.

Campbell, R. A. 2004. CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. *Fish. Res.,* 70(2-3): 209-227. https://doi.org/10.1016/j.fishres.2004.08.026.

Chan, B., Brosse, S., Hogan, Z., Ngor, P. and Lek, S. 2020. Influence of local habitat and climatic factors on the distribution of fish species in the Tonle Sap Lake. *Water*, 12(3): 786. https://doi.org/10.3390/w12030786.

Chen, D. G. 1997. *Fishery resources biology*. China Agriculture Press, Beijing, China, 187 pp. (In Chinese).

Chen, G. B., Li, Y. Z., Zhao, X. Y., Chen, Y. Z. and Jin, X. S. 2005. Acoustic assessment of commercial fish resources in the northern waters of South China Sea. *J. Fish. Sci. China,* 12(4): 445-451.

Chen, P., Niu, A. C., Liu, D. Y., Jiang, W. and Ma, B. 2018. Time series forecasting of temperatures using SARIMA: An example from Nanjing. *IOP Conf. Ser.: Mater. Sci. Eng.,* 394: 052024. https://doi.org/10.1088/1757-899X/394/5/052024.

Chung, M., Jorgensen, K. M., Trueman, C. N., Knutsen, H., Jorde, P. E. and Gronkjær, P. 2021. First measurements of field metabolic rate in wild juvenile fishes show strong thermal sensitivity but variations between sympatric ecotypes. *Oikos*, 130(2): 287-299. https://doi.org/10.1111/oik.07647.

Dong, M. 2016. *Ecological perspective: Population ecology*. Science Press., Beijing, China, 319 pp.

Fan, J. T., Chen, Z. Z., Zhang, J. and Feng, X. 2016. *Sthenoteuthis oualaniensis* fishing grounds analysis based on marine environmental factors and different weight coefficients in the Zhongxisha and Xisha Islands, South China Sea. *South China Fish. Sci.,* 12(4): 57-63.

Fan, J. T., Huang, Z. R., Xu, Y. W., Sun, M. S., Yan, R. and Chen, Z. Z. 2019. Analysis of *Priacanthus macracanthus* fishing grounds in the northern South China Sea based on sea surface temperature and depth. *J. Fish. Sci. China*, 26(1): 26-33.

Gu, Y. G., Lin, Q., Huang, H. H., Wang, L. G., Ning, J. J. and Du, F. Y. 2017. Heavy metals in fish tissues/stomach contents in four marine wild commercially valuable fish species from the western continental shelf of South China Sea. *Mar. Pollut. Bull.,* 114(2): 1125-1129. https://doi.org/10.1016/j.marpolbul.2016.10.040.

Han, W. Y., Wang, M. B. and Ma, K. M. 1990. Study on the lowest surface water temperature area in summer in China. The upwelling area along the east coast of Qiong Dong. *Oceanol. Limnol. Sin.,* 21(3): 267-275.

Helfenstein, U. 1991. The use of transfer function models, Intervention analysis and related time series methods in epidemiology. *Int. J. Epidemiol.*, 20(3): 808-815. https://doi.org/10.1093/ije/20.3.808.

Hengl, T., Heuvelink, G. B. M., Percec Tadic, M. and Pebesma, E. J. 2012. Spatio-temporal prediction of daily temperatures using time-series of MODIS LST images. *Theor. Appl. Climatol.*, 107(1-2): 265-277. https://doi.org/10.1007/s00704-011-0464-2.

Jabbar, M. A., Kamal, M. M., Boer, M., Suyasa, I. N. and Nurdin, E. 2017. Population dynamics of the red bigeye (*Priacanthus macracanthus* Cuvier, 1829) (Fish: Family Priacanthidae) in Palabuhanratu Bay, Indonesia. *Aquac. Aquar. Conserv. Legis.,* 10(5): 1198-1209.

Ji, S. J., Zhou, W. F., Cheng, T. F. and Chen, G. B. 2015. On the forecast and analysis of fishing grounds in the open South China Sea. *Mod. Fish. Inf.,* 30(2): 98-105.

Jia, X. P., Li, C. H. and Qiu, Y. S. 2005. *Investigation and evaluation of marine fishery resources in Guangdong Province and countermeasures for sustainable utilisation. China*. Ocean Press, Beijing, China, 538 pp. (In Chinese).

Jia, X. P., Li, Y. Z., Li, C. H., Qiu, Y. S. and Gan, J. L. 2004. *Fishery ecological environment and resources in South China Sea exclusive economic zone and continental shelf*. Science Press, Beijing, China, p. 358-472 (In Chinese).

Joung, S. J. and Chen, C. T. 1992. Age and growth of the big eye *Priacanthus macracanthus* from the surrounding water of Guei-Shan Island, Taiwan. *Nippon Suisan Gakk*, 58(3): 481-488. https://doi.org/10.2331/suisan.58.481.

Kim, J. Y., Jeong, H. C., Kim, H. and Kang, S. 2015. Forecasting the monthly abundance of anchovies in the South Sea of Korea using a univariate approach. *Fish. Res.,* 161: 293-302. https://doi.org/10.1016/j.fishres.2014.08.017.

Kuraiem, B. P., Knoff, M., Felizardo, N. N., Gomes, D. C. and Clemente, S. C. S. 2016. Nematode larvae infecting *Priacanthus arenatus* Cuvier, 1829 (Pisces: Teleostei) in Brazil. *An. Acad. Bras. Cienc.,* 88(2): 857-863. https://doi.org/10.1590/0001-3765201620150137.

Lester, R. J. G. and Watson, R. A. 1985. Growth, mortality, parasitism, and potential yields of two *Priacanthus* species in the South China Sea. *J. Fish Biol.,* 27(3): 307-318. https://doi.org/10.1111/j.1095-8649.1985.tb04032.x.

Li, L. 1990. A study on the summer upwellings in shelf waters west to Zhujiang River mouth. *J. Oceanogr. Taiwan Strait*, (4): 338-346.

Liu, C. J., Xia, H. Y. and Wang, D. X. 2010. The observation and analysis of eastern Guangdong coastal downwelling in the winter of 2006. *Acta Oceanol. Sin.,* 32(1): 1-9. https://doi.org/10.3788/HPLPB20102209.2186.

Liu, Q. Y., Jia, Q. Y., Yang, H. J. and Liu, Z. 2002. Seasonal variation mechanism of sea surface height in the north of the SCS. *Acta Oceanol. Sin.,* 24(S1): 134-141.

Liu, W., Lin, Z., Jiang, Y. and Huang, Z. 2011. Spatial distribution of demersal fishery resources in the continental shelf of the northern South China Sea. *J. Trop. Oceanogr.,* 30(5): 95-103.

Liu, Y. X., Wang, X. F., Chen, G. B., Lv, S. L. and Zeng, J. W. 2019. Spatiotemporal heterogeneity of bigeye resources in the northern South China Sea. *J. Fish. China*, 43(12): 2523-2532. https://doi.org/10.11964/jfc.20190111648.

Liu, Y. X., Wang, X. F., Lv, S. L., Zeng, J. W. and Chen, G. B. 2021. Spatial autocorrelation of bigeye resources in the northern South China Sea. *J. Fish. China*, 45(08): 1316-1373.

Liu, Z. N. and Yu, J. 2018. Response of Spatio-temporal distribution of fishery resources to mairne environment in the Northern South China Sea. *Anim. Husb. Feed Sci.,* 10(5-6): 311-317, 320.

Liu, Z. N., Yu, J, Chen, P. M., Yu, J. and Wang, Y. F. 2019. Relationship between the spatio-temporal distribution of light falling-net fishing ground and marine environment in the western Guangdong waters. *J. South. Agric.,* 50(4): 867-874.

Lu, Z. H., Zhu, Z. J. and Lin, X. P. 2010. Food habits of *Priacanthus macracanthus* in East China Sea region. *Mar. Fish.,* 32(2): 199-203. https://doi.org/10.3724/SP.J.1011.2010.01138.

Ma, J., Huang, J. L, Chen, J. H., Li, B., Zhao, J., Gao, C. X., Wang, X. F. and Tian, S. Q. 2020. Analysis of spatiotemporal fish density distribution and its influential factors based on generalised additive model (GAM) in the Yangtze River estuary. *J. Fish. China*, 44(6): 936-946.

Nelder, J. A. and Wedderburn, R. W. M. 1972. Generalised Linear Models. *J. R. Stat. Soc.,* 135(3): 370-384. https://doi.org/10.2307/2344614.

Qiu, Y. S., Zeng, X. G., Chen, T., Wang, Y. Z. and Yuan, W. W. 2008. *Fishery resources and management in the South China Sea*. China Taxation Press, Beijing, China, p. 115-178 (In Chinese).

R Development Core Team 2010. *A language and environment for statistical computing: reference index*. R Foundation for Statistical Computing, Vienna, Austria, 2057 pp.

Rooper, C., Ortiz, I., Hermann, A., Laman, N., Cheng, W., Kearney, K. and Aydin, K. 2020. Predicted shifts of groundfish distribution in the Eastern Bering Sea under climate change, with implications for fish populations and fisheries management. *ICES J. Mar. Sci.*, 78(1): 220-234. https://doi.org/10.1093/icesjms/fsaa215.

Samuel K. and Johnson, N. L. 1992. *Breakthroughs in statistics*. Springer-Verlag, New York, USA, p. 599-624.

Seetha, P. K., Zacharia, P. U., Sobhana, K. S. and Sivakami, S. 2018. Fishery, biology and stock status of *Priacanthus hamrur* (Forsskal, 1775) exploited off Kerala coast. *J. Mar. Biol. Ass. India*, 60(1): 27-32. https://doi.org/10.6024/jmbai.2018.60.1.2010-04.

Su, Z. F., Zhou, C. H., Liu, B. Y., Du, Y. Y. and Shao, Q. Q. 2002. A spatio-temporal pattern extracting model for fishing ground. *Acta Oceanol. Sin.,* 24(5): 46-56. https://doi.org/10.1007/s11769-002-0038-4.

Venables, W. N. and Dichmont, C. M. 2004a. GLMs, GAMs and GLMMs: An overview of theory for applications in fisheries research. *Fish. Res.,* 70(2-3): 319-337. https://doi.org/10.1016/j.fishres.2004.08.011.

Venables, W. N. and Dichmont, C. M. 2004b. A generalised linear model for catch allocation: an example from Australia's Northern Prawn Fishery. *Fish. Res.,* 70(2-3): 409-426. https://doi.org/10.1016/j.fishres.2004.08.017.

Wang, X. H., Lin, Z. J., Du, F. Y., Qiu, Y. S. and Sun, D. R. 2013. Fish species composition and community pattern in the continental shelf of northwestern South China Sea. *Acta Ecol. Sin*., 33(7): 2225-2235. https://doi.org/10.5846/stxb201112261975,

Wang, Y. P., Li, X. Q., Liu, Y. and Jiang, N. N. 2020. Evaluation and analysis of effects on the different interpolation temperature algorithms. *Inf. Technol.,* 44(6): 31-35.

Wu, S. N. and Chen, X. J. 2020. Relationship between the recruitment of the Pacific-cohort of chub mackerel (*Scomber japonicus*) and the influence factors on the spawning ground based on GLM and GAM. *J. Fish. China*, 44(1): 61-70.

Xie, E. G., Zhou, Y. B., Feng, F. and Wu, Q. E. 2020. Catch per unit effort (CPUE) standardization of purpleback flying squid *Sthenoteuthis oualaniensis* for Chinese large-scale lighting net fishery in the open sea of South China Sea. *J. Dalian Fish. Univ.,* 35(3): 439-446.

Xiong, D., Li, M., Li, Y. Z., Li, Y. F., Zhang, K. and Chen, Z. Z. 2016. Sequence analysis of the mitochondrial cytochrome b gene and identification of the *Priacanthus macracanthus* population in the South China Sea. *J. Fish. Sci. China*, 23: 188-197. https://doi.org/10.3724/SP.J.1118.2016.15114.

Xu, F. H. and Oey, L. Y. 2015. Seasonal SSH variability of the Northern South China Sea. *J. Phys. Oceanogr.,* 45(6): 1595-1609. https://doi.org/10.1175/JPO-D-14-0193.1.

You, S. B. and Yan, Y. 2017. Stepwise regression analysis and its application. *Stat. Decis.*, 000(14): 31-35.

Yu, C. D. and Yu, C. G. 2009. *Study on utilization of fishery resources and management of marine fishing operation in the south of Zhejiang Province*. China Ocean Press, Beijing, China, 190 pp.

Zhang, J., Yao, Z., Lin, L. S., Li, Y., Song, P. Q., Zhang, R. and Gao, T. X. 2016. Spatial distribution of biomass and fishery biology of main commercial fish in the mouth of Beibu Bay and the Southwestern waters of the Nansha Islands. *Period. Ocean Univ. China*, 46(11): 158-167.

Zhang, T. T., Zhang, T. and Hou, J. L. 2014. Application of spatial information technologies in monitoring and assessment of fishery resources and ecological environment. *Mar. Fish.,* 36(3): 272-281.

Zhang, Y. N. 2015. Regression analysis education statistics application based on R language. *J. Anshan Norm. Univ.,* 17(2): 63-68.

Zheng, B., Chen, X. J. and Li, G. 2008. Relationship between the resource and fishing ground of mackerel and environmental factors based on GAM and GLM models in the East China Sea and Yellow Sea. *J. Fish. China*, 32(3): 379-386. https://doi.org/10.3724/SP.J.1035.2008.00038.

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