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Impact of Main Factors on the Catch of *Portunus trituberculatus* in the Northern East China Sea

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ABSTRACT

Generalized additive models (GAM) were used to analyze the relationships between the catch of *Portunus trituberculatus* in the northern East China Sea, and 6 main impact factors, which include the number of main catch vessel (NMV), power of main catch vessel (PMV), number of trawl vessel (NTV), power of trawl vessel (PTV), release number of larval crab (RELE), and sea surface temperature (SST). The results showed that the interpretation ratio (IR) of the 6 factors reached 83.76%, within which the IR of the RELE is the largest (26.02%). The IRs of NMV and PTV also exceed 20% (20.21% and 20.10%, respectively). The IRs of SST, PMV and NTV are similar, and all are between 5.6% and 6%. The catch of *P. trituberculatus* positively correlated with the fishing efforts of main catch vessels, but showed negative correlation with those of bycatch vessels (trawl vessels). This indicates that trawl fishing may give negative impact on *P. trituberculatus* fishery, i.e. the decrease of fishing effort of trawls in recent years resulted in the decrease of the catch of *P. trituberculatus*. But these catches were small compared with those of main catch fishing vessels. Thus, the total catches of *P. trituberculatus* become large. The catch of *P. trituberculatus* increased with the increase of SST. RELE can impact the catch since they present the same trend, but it is not as critical as imagined. Therefore, the variation of the catch of *P. trituberculatus* in the northern East China Sea was synthetically affected by multiple factors. More studies should be carried out to explore other potential factors that may affect the catch, and find out the underlying mechanisms.

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Authors' Contributions
YW presented concept and design of the study TY analysed the data and helped YW in writing the manuscript. XW edited manuscript and performed statistical analysis. CZ helped in data acquisition and literature research.

Key words
***Portunus trituberculatus*, Generalized additive model (GAM), Catch, Impact factors, The Northern East China Sea**

INTRODUCTION

Portunus trituberculatus is the world's largest crab fishery, accounting for about one quarter of the crabs caught commercially worldwide (Liu *et al*., 2013), and it is also one of the most important fisheries in China. It was reported that the catch of *P. trituberculatus* in China increased from 110×10^6 kg in 1980s to more than 400×10^6 kg in 2012 (Department of agriculture, 2013). The catch of *P. trituberculatus* occurs in China in three main fishing areas: the East China Sea, the Yellow Sea, and the Bohai Sea (Liu *et al*., 2013), among which the catch form the East China Sea account for the highest proportion (~50%), within which the northern East China Sea account for more than 40% (Song *et al*., 2003; Yu *et al*., 2003).

The drift gill net fishery boomed in 1980s in the northern East China Sea, and then the crab resources were fully exploited. In the middle of 1980s, the catch of *P. trituberculatus* exceed 50×10^6 kg at the first time (Wu *et al*., 1996). At the early of 1990s, after the crab pot was used in the crab fisheries, it was rapidly popularized, and became one of the main fishing gears catching *P. trituberculatus*. Thus, at the middle of 1990s, the catch of *P. trituberculatus* exceed 60×10^6 kg (Song *et al*., 2003). With the increase of fishing effort, the abundance of *P. trituberculatus* continuously decreased. From 1983, the breeding *P. trituberculatus* were not allowed to catch during May and June in the northern East China Sea to protect the abundance (Yu *et al*., 2003). In 2000, the crab pot vessels were not allowed to go out fishing during the closed fishing season at the first time in the East China Sea (Yu *et al*., 2004), and from 2001, the *P. trituberculatus* was on the list of species to enhancement and releasing (Wang *et al*., 2009). After 2000, the catch of *P. trituberculatus* did not continuously increase, but fluctuated up and down. However, from 2010 to 2014, the catch of *P. trituberculatus* increased year after year, and the annual average increasing rate was about 32% (Zhejiang Provincial Bureau of statistics, 2014). The closed fishing season and enhancement do have effect on the recovery of abundance, but the catch of *P. trituberculatus* increased after above policies implemented for about 10 years, we believe there must be other reasons. Some scholars proposed other assumptions, such as the changes of sea water temperature, natural enemies, and growth characteristics, etc., but the experts are still unable to give clear explanation.

In China, *P. trituberculatus* is one of the most important aquaculture species, and annual output is more than 100×10^6 kg (Department of agriculture, 2014). Although the research about breed, disease, nutrition and aquaculture technique etc. have been carried out in depth (Li *et al*., 2013, 2014; Mu *et al*., 2014; Wang *et al*., 2016), the natural resource of *P. trituberculatus* should never be

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ignored. This is not only because the catch of natural *P. trituberculatus* is still occupy a major share of the total output, but it play an important ecological significant. *P. trituberculatus* is not the absolute dominant species in the northern East China Sea, but its nutritional status is critical, and the changes of growth and abundance will affect the community structure. Therefore, in this research, taking the northern East China Sea as a case study, we explore the relationships between the catch of *P. trituberculatus* and the potential factors that may affect the variation of its abundance, which is important to the effective protection and rational development of this resource.

MATERIALS AND METHODS

Materials

The data that needed for the research, including the catch, fishing effort, number of released individual of *P. trituberculatus* in the northern East China Sea from 2010 to 2015, were obtained from the administrative department for fisheries (Fig. 1). The catch and fishing effort covered the vessels both aim *P. trituberculatus* as target species and companion species. Fishing efforts included the numbers and powers of drift gill net vessel, crab pot vessel and trawl vessels. All these vessels were fishing on the offshore fishing grounds (Fig. 2). The sea surface temperature (SST) came from RI/LDEO Climate Data Library of Columbia University.

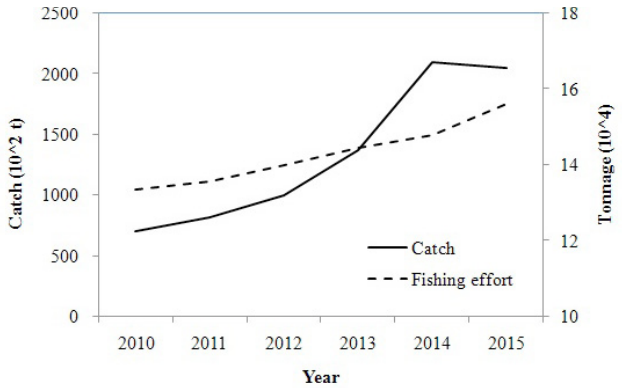

Fig. 1. Annual statistical data of *Portunus trituberculatus* from 2010 to 2015 in the northern East China Sea.

Methods

The functional relationship between catch (natural log-transformed) and other variables was developed as non-linear using generalized additive model (GAM). The variable included the number of trawl vessel, power of trawl vessel, number of main catch vessel, power of main catch vessel, number of released individual, and sea surface temperature.

The GAM is an extension of generalized linear model, which replaces linear predictors with an additive predictor. Its general form can be written as:

$$Y = \alpha + \sum_{j=1}^{p} f_j(x_j) + \varepsilon \qquad (1)$$

where α represents the intercept term in the fitted model, f_i is a smooth function (a spline or a loess smoother); x_i are the independent variables; $\mathrm{var}(\varepsilon)=\sigma^2$ and $E(\varepsilon)=0$ (Tian *et al*., 2009; Wang *et al*., 2012). GAM allows for rather flexible specification of the dependence of the response on the covariates, but by specifying the model only in terms of 'smooth functions', rather than detailed parametric relationships, it is possible to avoid the sort of cumbersome and unwieldy models when using GLM.

The error of natural log-transformed catch was assumed to be normally distributed in the GAM modeling. Based on the obtained information, we used the following GAM:

$$\ln(catch) = s(NTV) + s(PTV) + s(NMV) + s(PMV) + s(RELE) + s(SST) + \varepsilon \qquad (2)$$

where NTV and NMV represent the numbers of trawl vessels and main catch vessels, respectively; PTV and PMV are powers of trawl vessels and main catch vessels; RELE is released number of larval crab, SST is the sea surface temperature.

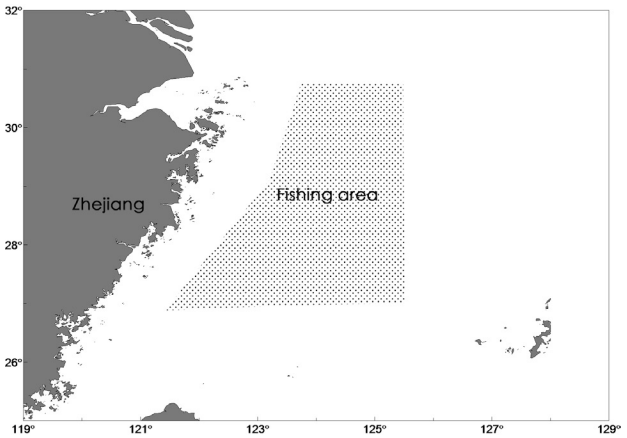

Fig. 2. Fishing area of *Portunus trituberculatus* in the northern East China Sea.

RESULTS

Interpretation ratios of the variables

Table I shows the interpretation ratio (IR) for each variable, and the accumulated interpretation ratios indicate the changes of IR when adding the each variable step by step. The total IRs of the 6 variables reach 83.76%, within which the IR of the RELE is the largest (26.02%), and the IRs of other two variables, NMV and PTV, also exceed 20% (Table I). For other 3 variables (SST, PMV and NTV),

Table I.- Analysis of interpretation ratio for GAM fitted to the catch data of *Portunus trituberculatus* in the northern East China Sea.

Variable	Interpretation ratio (%)	Accumulated interpretation ratio (%)
Release number of larval crab (RELE)	26.02	26.02
Number of main catch vessel (NMV)	20.21	46.23
Power of trawl vessel (PTV)	20.10	66.33
Sea surface temperature (SST)	5.98	72.32
Power of main catch vessel (PMV)	5.84	78.15
Number of trawl vessel (NTV)	5.61	83.76

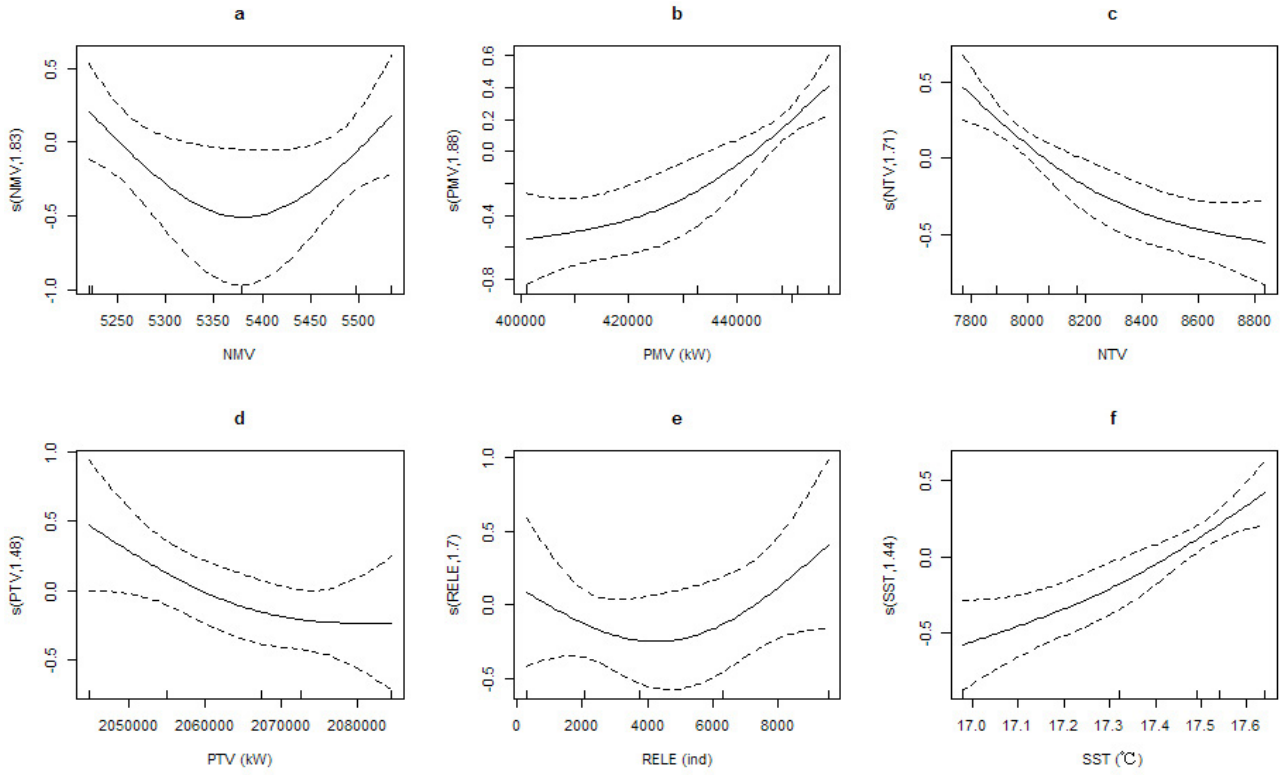

Fig. 3. Impact of (a) the number of main catch vessel (NMV), (b) the power of main catch vessel (PMV), (c) the number of trawl vessel (NTV), (d) the power of trawl vessel (PTV), (e) the release number of larval crab (RELE), and (f) the sea surface temperature (SST) on the catch of *Portunus trituberculatus* in the northern East China sea.

their IRs are similar, which are between 5.6% and 6%.

Main catch vessels and catch

The main catch fishing gears in the northern East China Sea including drift gill net and crab pot. Therefore, the NMV and PMV in Figures 3a and 3b represent total number and power of these two kinds of vessels, respectively. Both NMV and PMV can affect catch, but catch has high correlation relationship with PMV than with NMV (Figs. 3a, b). When NMV increases, the catch of *P. trituberculatus* decrease firstly and then increase (Fig. 3a), indicating the number of main catch fishing vessel does not directly has positive or negative correlation relationship with catch. While, catch increase with the increase of PMV (Fig. 3b), which means the power of vessels is a more appropriate fishing effort indicator than NMV.

Bycatch vessels and catch

Trawls capture *P. trituberculatus* as bycatch, and their bycatch phenomena are the most serious among all kinds of fishing gears. Figures 3c and 3d show the impact

of NTV and PTV on the catch. It is interesting that the trends of NTV and PTV are almost contrary to those of NMV and PMV. When the number and power of trawl vessels decrease, the catch of *P. trituberculatus* increase, this indicates that the trawl fisheries may have negative impacts on the catch of *P. trituberculatus*.

Release number, sea surface temperature and catch

Both RELE and SST can affect the catch of *P. trituberculatus* (Figs. 3e, f). With the increase of RELE, the catch decrease firstly then increase (Fig. 3e). This shows that the RELE may not affect the trends of catch directly or immediately. On the contrary, SST positively correlated with catch, *i.e.* catch increase continuously with the increase of SST (Fig. 3f).

DISCUSSION

Since 2010, the catch of *P. trituberculatus* in the northern East China Sea increased rapidly, and the price of *P. trituberculatus* declined substantially. Although, the fishermen returned fully loaded, their income did not increase at all. Many scientists paid attentions to this issue, and wanted to find the answer why the catch of *P. trituberculatus* continuously increased. In recent years, the double controls (controls of vessel number and power) measure was implemented by the government, so the fishing effort can not increase as fast as catch. Therefore, the rapid change of catch must be related with other factors besides fishing effort. Many possible reasons were proposed, such as the rise of temperature, enhancement and release, predation pressure (less fishes lead to less predation pressure on juvenile crab), etc. Each reason seems reasonable, and we can imagine that the change of catch must be the results of combined effects. Our research results also proved this.

The selected 6 factors in this research accounted for 83.76% of all the potential factors that may affect the catch of *P. trituberculatus*. RELE is the factor with the highest interpretation ratio (26.02%), which means RELE gave the most impact on the variation of catch among these 6 factors. Based on the common sense, catch should be increase with the increase of release number. But our result does not show positive correlation between catch and RELE (Fig. 3e). Actually, before 2015 the catch of *P. trituberculatus* increased with annual growth rate of 32%, meanwhile the release number also increased with annual growth rate of about 67% during this period (personal communication with fisheries management personnel). Thus, on the surface, they showed positive correlation relationship. But in 2015, the government cut about 97% release number of *P. trituberculatus* compared with that of 2014 to check the impact of RELE on the catch of *P. trituberculatus*, *i.e.* if the catch of *P. trituberculatus* also decreases greatly, the contribution of RELE on catch will be significant. The fact is that the catch of *P. trituberculatus* in 2015 decrease only about 2.5% compared with that in 2014. From these results we can see that RELE can impact the catch since they present the same trend, but is not as critical as imagined. The dramatically decreased RELE did not significantly impact catch. Therefore, besides RELE, there must be other factors give combined effects on catch. The decrease of RELE may lead to more serious effect in the following years, but at present it is hard to predict. In any case, we do not recommend changing the RELE dramatically in such short period before the ecological consequences are clear. From this point of view, the studies of scientific release capacity and evaluation should be carried out.

In this research, we chose the numbers and powers of main catch and bycatch fishing gears as fishing effort indices. The number of main catch fishing vessels, including drift gill net and crab pot vessels, was fluctuated, but the power increases continuously, which showed positive correlation with catch (Fig. 3b). Different from the main catch fishing gears, both the number and power of bycatch fishing gears (trawls selected in this research) showed negative correlation with catch (Figs. 3c, d). This result is interesting. Theoretically, fishing effort of bycatch gear should have similar effect as that of main catch gear, but in this research, two kinds of fishing effort present different impacts on catch. This indicates that trawl fishing may give negative impact on *P. trituberculatus* fishery, *i.e.* when fishing effort of trawls decreased in recent years, their corresponding catch of *P. trituberculatus* also decreased. But the catches of bycatch fishing vessels, compared with those of main catch fishing vessels, were small. Thus, the total catches of *P. trituberculatus* become large. More studies are needed to reveal the real reasons.

The sea temperature annually increases about 0.26^0C averagely within the recent 5 years, and this trend coincides with that of catch. High temperature can promote the reproduction and growth of juvenile crabs. Under normal circumstances, *P. trituberculatus* spawn in the spring (April to May) and autumn (October to November), and mainly in spring. When sea temperature increase, crabs spawning in autumn will increase, thus catch in August also become large. Take 2013 as an example, the number of parent crab in August 2013 increased by about 20% compared with that in 2012 (City Express, 2013). Thus, we can anticipate that SST positively correlates with catch (Fig. 3f).

P. trituberculatus belongs to the first class carnivorous animal, and the trophic level is about 3.3. Seldom species can predate on adult *P. trituberculatus* duo to its hard shell. But the egg, larva and the soft shell individuals during molting period are main target preys for many fishes. Although, the trophic level is high, *P. trituberculatus* plays an important role in connecting the nutrition relationship between upper and lower trophic levels. If the abundance

of *P. trituberculatus* changes unusually, the trophic relationships in the community will inevitably be affected, and then the balance of the community and even that of the ecology will be break. Therefore, it is necessary to study the relationships between catch or abundance and potential impact factors, and explore the underlying mechanisms. Although, *P. trituberculatus* is such an important economic species in China, seldom studies about stock assessment and management have been carried out. The main researches about *P. trituberculatus* mainly focused on biology and aquaculture techniques (Li *et al*., 2013, 2014; Mu *et al*., 2014; Wang *et al*., 2016), and the scientific guidance for the exploitation and management of *P. trituberculatus* in China is absent. Therefore, in future researches, we will do stock assessment to give scientific suggestions for this species to improve the management effectiveness. Moreover, we will also use more statistical and survey data to analyze other potential factors that may impact the variations of catch and abundance index (CPUE).

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Conflict of interest statement

The authors have declared no conflict of interest.

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