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Spawner-recruit analysis of *Portunus* (*Portunus*) *trituberculatus* (Miers, 1876) in the case of stock enhancement implementation: a case study in Zhejiang sea area, China

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Abstract

Portunus (Portunus) trituberculatus (Miers, 1876) is one of the most important economic species in the East China Sea. In recent years, the catch of *P. trituberculatus* in this sea area dramatically increased. Some researches owing this to the implementation of stock enhancement, and encourage its development. However, besides the increased catch, the potential impact of releasing on the spawner-recruit (S-R) relationship is neglected. In this research, we analyzed the S-R relationships using the data of *P. trituberculatus* in a typical sea area (Zhejiang seas area) in the East China Sea from 1995 to 2015, and found that stock enhancement can greatly impact the original S-R relationship. We separated above period into 2 stages (the 1st stage is from 1995 to 2010, and the 2nd stage is from 2011 to 2015), which represented the periods without and with the additive effect of stock enhancement on wild population, respectively. Different S-R models are necessary for wild population and release stock. Two Ricker S-R models were built for these 2 stages, which are $R = 10.53Se^{-0.00032S}$ and $R = 14.26Se^{-0.00019S}$. The survival rate of the release stock is much higher than that of wild population, and the reproductive rate is also high for the release stock. The S-R relationships of release stock and wild population are different. The reproductive rate (R/P) of release stock is higher than that of wild population.

Keywords: Spawner-recruit relationship, *Portunus (Portunus) trituberculatus* (Miers, 1876), stock enhancement, Ricker model

Introduction

Spawner-recruit (S-R) relationship is one of the most important and generally most difficult problems in biological assessment of fisheries (Hilborn and Walters, 1992). It is important not only because the relationship describe the ability of a stock to maintain abundance in response to intensive fishing pressure, but also because it provide a basis for predicting the range of recruitment that is expected for a given size of spawning stock (Jennings *et al*., 2001).Much effort has been directed to the study of the S-R relationships and the factors that may impact on them, including biological factors, environmental factors, temporal and spatial factors and stock enhancement, etc. (Haddon, 2001; Sinclair and Crawford, 2005; Maunder and Deriso, 2013; Hühn*et al*., 2014).

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Stock enhancement is one of the oldest, yet most controversial and least well-understood approaches to fisheries management. Stocking of hatchery fish has been practiced on a large scale since the mid-nineteenth century, and systematic transfers of wild juveniles probably have a much longer history (Lorenzen*et al.*, 2001; Lorenzen, 2005). Stock enhancement is the release to the wild of juveniles (fish or invertebrate) rose in hatcheries. Hatcheries raise species from egg to juvenile, which are the most vulnerable stages in the life cycle of marine animals. Survival in hatcheries is greatly increased due to lack of predators and abundant food. Therefore, stock enhancementhas become a fisheries management approach used to recover depleted species populations that have faced threats such as overfishing, habitat loss, or ocean acidification (Lorenzen, 2005).

In China, stock enhancement was firstly implemented during 1950s. After 1980s, the scale of stock enhancement gradually increased (Luo and Zhang, 2014). Now, the stock enhancement carries out in all the 4 sea areas (the Bohai Sea, the yellow Sea, the East China Sea and the South China Sea) and inland provinces in China (Luo and Zhang, 2014).From 2004-2013, 245 species (not including aquatic plants) were released, including fish, crustacean, mollusk, etc., and the total number exceeded 230 billion (Luo and Zhang, 2014). The effect of stock enhancement in China, at least on population level, is significant. The abundance of many economic species increased, and some of these resources recovered.Among these species,*Portunus* (*Portunus*) *trituberculatus* (Miers, 1876) obtained the most marked effect.*P. trituberculatus* is one of the important economic species in Zhejiang sea area, and it is also the largest crab fishery in this area (Song, *et al*., 2003; Yu, *et al*., 2004).*P. trituberculatus* was added to the list of species to enhancement in 2001 in Zhejiang sea area (Wang *et al*., 2009). At first, the release number is small (several million individuals per year), but after 2010, the release number dramatically increased. In 2011 more than20 million juveniles were released, and this number continuously increased, in 2014 it exceeded 95 million. Since then, the catch of *P. trituberculatus* in Zhejiang sea area increased sharply. However, under such condition, the impact of releasing on the abundance and recruitment can not be ignored any longer. The relationship between spawner and recruit will be changed, the original S-R relationship built when no releasing implementedcan not describe the relationship anymore after the stock enhanced. In this paper, we analyzed the S-R relationships of *P. trituberculatus*before and after the impact of stock enhancement can be ignored. We provided a method for separating the S-R relationship of wild stock from releasing stock when the experiments such as tag-recapture and fecundity were absent. This may help to improve the results of stock assessment and management strategy evaluation analyses.

Materials and Methods

Materials

The catch and release data of *P. trituberculatus* in Zhejiang province were obtained from the administrative department for fisheries of Zhejiang. Catch included the data from 1995 to 2015, while release data include the number released from 2011 to 2015. Although the stock enhancement of *P. trituberculatus* started from 2001, the release number was small before 2010, and no detailed information (like release process and number, etc.) were recorded.

P. trituberculatus samples were obtained each month from May 2015 to May 2016 (closed fishing season was not included) from vessels that fishing in Zhejiang sea area (Fig. 1) both aim *P. trituberculatus* as target species

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and companion species. Sampling vessels included drift gill net vessels, crab pot vessels and trawl vessels. Totally, 769 samples were collected.

Methods

2.2.1 Separation of carapace width groups

For each sampled individual, carapace width (mm), carapace length (mm) and wet body weight (g) were measured (Fig. 2). Because the age of *P. trituberculatus* is difficult to determined, all the analyses were based on carapace width. In the management regulations for *P. trituberculatus*, individuals with carapace width shorter than 60mm are treated as immature (Local standard of Zhejiang Province, DB33/T949-2014), and are forbidden to catch. Thus, we treated them as recruit populationin this research. The total annual catch (weight) of *P. trituberculatus* in the statistical yearbook is just a number, neither age-based nor length-based. Therefore, we separated the total catch into 4 carapace width groups (<60mm, 60mm~110mm, 110mm~150mm and >150mm) based on the carapace width proportions of the 4 groups in the samples. The catch composition by weight for all width groups could be calculated by multiplying the average weight with the corresponding number in each group. Therefore, the ratios of the catch weight for all width groups could also be calculated, which were applied to the total catches from 1995 to 2012, and then the total catches were separated by width. But just as mentioned above, the*P. trituberculatus*with carapace width shorter than 60mm (i.e. the recruit population) are protected, they were seldom appeared in our samples. Thus, the number of recruitment was predicted using Eq. 1:

$$N_{L+\Delta L,a+\Delta a} = N_{L,a} e^{-Z_{L,a}} \quad (1)$$

where $N_{L,t}$ represents abundance of *P. trituberculatus* for width group$L$ in year a. $\Delta L$is the increase of width, and Δa is the corresponding time when width increase ΔL.$Z_{L,a}$ representsthe coefficient oftotal mortality of width L(L was separated into 2 groups for mortalities estimations, i.e. $L \geq 60$mm and $L<60$mm) in year$a$, which equals to the sum of the coefficient of natural mortality (M)and fishing mortality (F): $Z_{L,a} = M_L + F_{L,a}$.

2.2.2 Estimation of coefficients of mortality

Length-based catch curve method was used to estimate Z using the latest 3 years' catch data, and the estimated Z was specified as the total mortality in the latest year, i.e. $Z_{\geq 60,\ 2015}$.M was assumed constant through year, but different for groups longer than 60mm with that shorter one. When carapace width is longer than 60mm, M is constant and is estimated using Eq. 2 when L=60mm:

$$M_{\geq 60} = M_1 \frac{1}{L} \quad (2)$$

whereM_1 is the average M in wild, and is 15yr^{-1} at unit length of 10mm (Lorenzen 1996, 2000). Thus, $M_{\geq 60} = 0.25$ yr^{-1}. For the individuals with carapace width shorter than 60mm, $M_{<60} = 4M_{\geq 60}$ was used, because the growth parameter (K) estimated from immature population was about 4 times of that obtained from mature population (Sun, *et al.*, 1984). Additionally, because the release individuals are artificial breeding, and are hatchery released in II juvenile stage (with carapace width of about 6mm), their survival rate are definitely

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higher than that of wild recruitment. Therefore, the *M* of the recruitment of the release stock is assumed half of that wild recruitment ($M_{<60} = 2M_{<60,release}$).

F was assumed knife edge, i.e. selectivity was 0 for group shorter than 60mm, and equaled to 1 for groups larger than 60mm. The coefficient of fishing mortality in the latest year could be estimated as $F_{\geq 60,2015} = Z_{\geq 60,2015} - M_{\geq 60}$, thus $F_{\geq 60,2015}$ was treated as a standard, and *F* from 1995 to 2014 ($F_{L,a}$) were calculated according to the standard, which were varied with fishing effort during these years. Then, the coefficients of total mortality were obtained through $M_L + F_{L,a}$.

2.2.3 Spawner-recruit relationship

The S-R relationship was built based on the Ricker model:

$$R = \alpha S e^{-\beta S} \qquad (3)$$

where*R* is recruitment and *S* is spawner, and recruitment was assumed 1 year lagged; *α*and*β*are two parameters.

The catch data of *P. trituberculatus* that we could obtain are from 1995 to 2015. The release of *P. trituberculatus* started from 2001, but the release number was small before 2010, and no detailed information was recorded. Given the above facts, we separated the time period into 2 stages. The first stage is from 1995 to 2010, which reflected the S-R relationship of wild population; the second stage is from 2011 to 2015, during this stage a multi-S-R relationships played a role, i.e. both spawner and recruitment were composed of wild population and release stock. For these 2 stages, we built the S-R relationships separately. In the second stage, the spawner abundances of release stock for different years were estimated using Eq. 1 since the II juvenile crabs were released. The recruitment of the wild population from 2011 to 2015 were estimated using the S-R relationship obtained in the first stage, then the recruitment of the release stock during 2011 and 2015 were calculated by subtracting the estimated recruitment of the wild population from the total observed recruitment. Thus, the S-R relationship of the release stock from 2011 to 2015 can be built.

Results

3.1 S-R relationship using both wild and release data

When using all the data of spawner abundance and recruitment (add wild and release data together), we obtained the S-R relationship representing as Fig. 3. We can see thatthis curve is concave upward, and is inconsistent with the Ricker model. It is obvious that the data from 2011 to 2014 completely change the trend of S-R curve (Fig. 3). We believe this relationship is unreasonable, and the most reasonable explanation is that the combination of both wild and release data distort the real S-R relationship, or the wild population and release stock have different S-R features. Therefore, we built the S-R relationship separately based on different stages.

3.2 S-R relationship of wild population

The data in the first stage (from 1995 to 2010) were used to build the S-R relationship of wild population, and the specific Riker model is shown as Eq. 4:

$$R = 10.53 S e^{-0.00032S} \qquad (4)$$

and the S-R curve is represented in Fig. 4. From Fig. 4 we can see that the wildspawner abundance varied between about 4 billion to 6 billion, and recruitment varied between about 7 billion to 13 billion. Even during the

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years when large amount of crab were released (from 2011 to 2015), the spawner abundance and recruitment of wild population were not greatly fluctuated compared with before (see the circles the triangles in Fig. 4).The S-R relationship of wild population presents the characteristic of density-dependent, and the spawner abundance and recruitment are not in their optimal situation (Fig. 4). Appropriate increase of fishing intensity for the wild population may increase its recruitment.

3.2 S-R relationship of release stock

The S-R relationship for the release stock was built based on thespawner abundance and recruitment in the second stage (Fig. 5). Although the data are limited, the observed data are well fitted with the estimated curve (Fig. 5), and Eq.5 is the corresponding Ricker model.

$$R = 14.26Se^{-0.00019S} \qquad (5)$$

From Fig. 5 we can see that recruitment come from release stock increased dramatically since 2011. Averagely, the reproductive rate (R/P) of release stock is larger than that of wild population (Figs. 3 and 4). During 2013 and 2014, the recruitment come from the release stock reached the peak, which indicates that from the recruit point of view, under such conditions (including environment and fishing, etc.) the release number in 2013 and 2014, i.e. 80 million per year, may be appropriate.

Discussion

Stocking of fish into self-reproducing stocks—so-called compensatory stocking (Cowx, 1994) or stock enhancement when the aim is to elevate fisheries yield (Lorenzen*et al*. 2012)—is frequently conducted across the globe (Welcomme and Bartley, 1998). This has been reflected in the *P. trituberculatus* resource. In the past 5 years, the catch and CPUE of *P. trituberculatus* uncoordinatedly increased compared with fishing effort and environmental factors. Although no affirmative conclusions can be made at present, we can not deny the role of stock enhancement.

Generally speaking, the catch of *P. trituberculatus*were negatively correlated with fishing effort before 2011 (FAO, 2016), and there was no obvious continuous decrease before stock enhancement implemented in 2001. Even after the implementation of the stock enhancement, the catch and CPUE still fluctuated up and down through years. This feature was existent until 2011, when large amount of juvenile crab werereleased. Then in the following 4 years, catch, fishing effort and CPUE all increased. In 2015, the government cut about 97% release number of *P. trituberculatus* compared with that of 2014 to check the impact of stock enhancement on catch. The fact is that the catch and CPUE of *P. trituberculatus* in 2015 decrease only about 2.5% and 7.7%, respectively, compared with that in 2014.Thus we can imaginerelease stock has begun to take shape in the seas area, which may affect the dynamics of wild population, including the original S-R relationship.

S-R relationship is a key point for population dynamics, and it is also critical for the sustainability of the population.Therefore, in order to improve the level of recruitment, stock enhancement, which is one of the most important measures for this, is implemented. Substantial scientific and heated public debate surrounds the question of whether stocking fish into self-sustaining stocks indeed produces additive effects or simply replaces wild recruitment (e.g., Leber,*et al*. 1995; Walters and Martell, 2004; Young, 2013). Additive effects of experimental stock enhancementhave been documented in several situations (Leber*et al*. 1995; Brennan *et al*. 2008), but there are equally many studies that reported failed stocking success, particularly when natural

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recruitment of the stock-enhanced species was present in the recipient water body (Li *et al*. 1996; Skov*et al*. 2011; Young 2013).Therefore, there is still no definite conclusion has been made that whether the stock enhancement has potential additive effects on the natural recruitment (e.g., Li *et al*. 1996; Brennan *et al*. 2008). From this study we can see that stock enhancement may impact the recruitment of *P. trituberculatus*. TheS-R relationship is totally different before and after a large amount juvenile crabs were released. We can not conclude that this feature is specific to *P. trituberculatus* or universal to crustaceans or other species. But for *P. trituberculatus*, different S-R relationships are necessary for wild population and release stock, because accurate S-R relationship is very important for the prediction of variation of abundance and the effective application of management strategy evaluation.

In this study, we built S-R relationship for wild population and release stock, respectively. For the wild population, S-R is not in the optimal state, and spawner abundance is larger than the level for the maximum R/P (Fig. 4), which indicates that the abundance of *P. trituberculatus* is large. One of the characteristic of *P. trituberculatus* resource is periodic outbreak, and we guess that *P. trituberculatus* may be in its outbreak period now. For the release stock, the survival rate is much higher than that of wild population (Figs. 3 and 4), and then the reproductive rate is also high. This may because the release stock is usually small, and can not surpass density-dependent mortality (Lorenzen 2000, 2005).Thus, we guess the release stock is not well combined with the wild population, so that they display totally different S-R relationships. For this problem, we will do further analyses to reveal the possible reasons.

In this research, we built the S-R relationship based on survey, catch and release data. We neither unpack the recruitment, nor do the experiments about fecundity. There may also be interaction effect between wild population and release stock, which may impact the levels of both recruitments. Additionally, long period data can improve the accuracy of the S-R relationship, and other environmental factors (like temperature, salinity, etc.) can also impact the S-R relationship. Therefore, in future studies, we will do the fecundity experiment of mature *P. trituberculatus*, and study each step of the recruit process intensively. We will also continue collect more data and add important environmental factors into the analysis S-R relationship.

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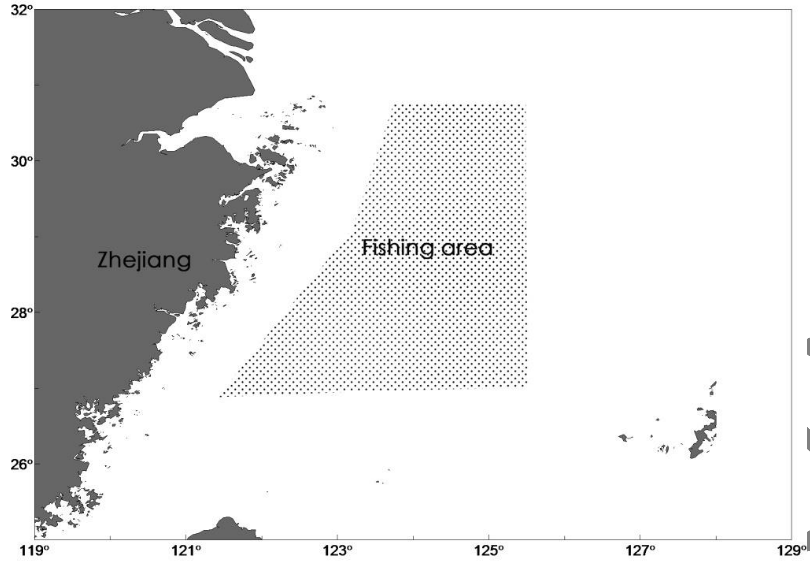

Figure 1. Fishing area of *Portunus*(*Portunus*) *trituberculatus* (Miers, 1876) in Zhejiang sea areas.

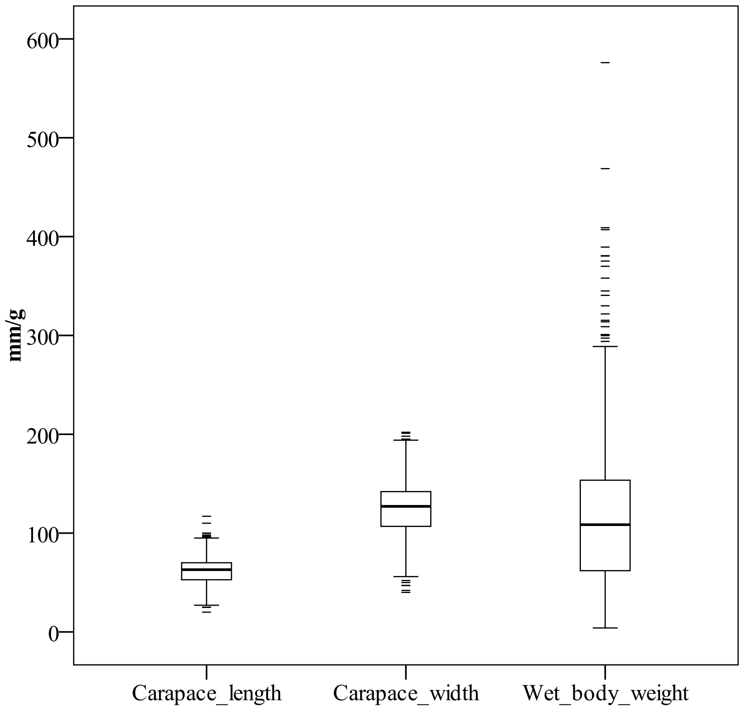

Figure 2. The measurement ranges of carapace width (mm), carapace length (mm) and wet body weight (k) for all the sampled individuals of *Portunus* (*Portunus*) *trituberculatus* (Miers, 1876) in Zhejiang sea areas.

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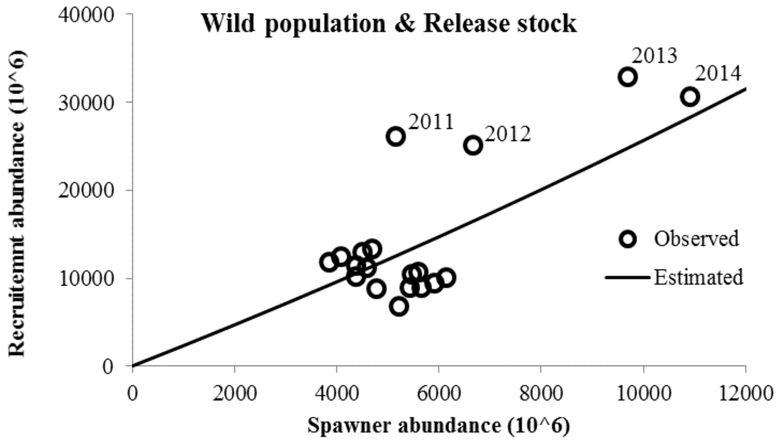

Figure 3. The spawner-recruit relationship of *Portunus* (*Portunus*) *trituberculatus* (Miers, 1876) in Zhejiang sea areas using both wild and release data.

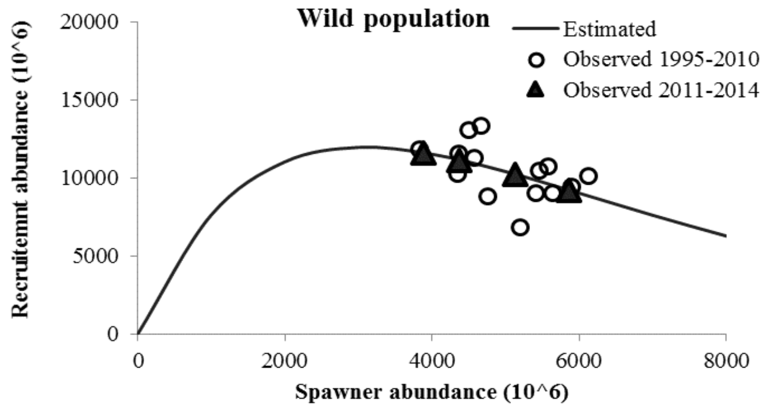

Figure 4. The spawner-recruit relationship of wild *Portunus* (*Portunus*) *trituberculatus* (Miers, 1876) in Zhejiang sea areas. Circle represents the observed data from 1995 to 2010, and triangle represents the observed data from 2011 to 2014.

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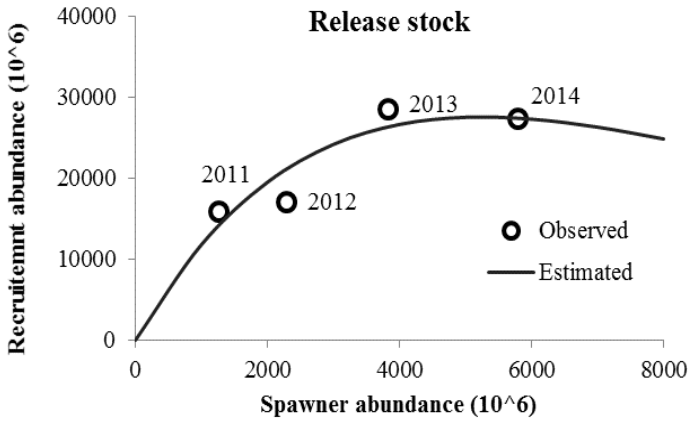

Figure 5. The spawner-recruit relationship of release stock of *Portunus* (*Portunus*) *trituberculatus* (Miers, 1876) in Zhejiang sea areas.