Population Dynamics of *Metapenaeus ensis* (Decapoda: Penaeidae) in a Coastal Region of the Mekong Delta, Vietnam

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ABSTRACT

The greasyback shrimp, *Metapenaeus ensis*, was studied in the Ganh Hao River, in a coastal region of the Mekong Delta in Vietnam, between February and December 2010, at six stations extending 30 km from the estuary. The results are as follows for males and females. The carapace lengths were 14.5–33.5 mm and 14.4–35.5 mm, the asymptotic carapace lengths were 35.2 and 37.3 mm, growth coefficients were 1.6 year^{-1} and 1.5 year^{-1}, and longevities were 1.8 and 2 years, respectively. Depending on the level of migration indices, for males and females, the total mortality coefficients were 3.7–5.0 year^{-1} and 4.1–4.9 year^{-1}, fishing mortality coefficients were 1.4–2.7 and 2.4–3.2 year^{-1}, the exploitation rates (E_α) were 0.38–0.54 and 0.59–0.65, and the maximum exploitation rates ($E\max_\alpha$) were 0.4–0.70 and 0.6–0.8, respectively. The natural mortality coefficients were 2.3 year^{-1} for males and 1.7 year^{-1} for females, respectively. These results demonstrate that *M. ensis* is still underexploited ($E_\alpha < E\max_\alpha$). However, large proportion of small shrimp is caught year round; it is a waste of natural resources and can deplete the resource in the future.

Introduction

Aquatic resources play an important role in developing countries, because they not only contribute to the daily livelihood of the population, but also provide significant nutrition for the local communities, as in Southeast Asia (Smith, 2003). In the Mekong Delta in Vietnam, 17.2 million people occupy an area of about 39,000 km^2, and 77.2% of them live in rural and coastal regions (Statistical Yearbook of Vietnam, 2010). Therefore, this community depends heavily on aquatic resources, which contribute significantly to both the incomes and diets of the population (Ministry of Fisheries, 2006).

The greasyback shrimp, *Metapenaeus ensis,* (De Haan 1844), is a species of the penaeid family, and is a very important component of estuarine and marine systems in the tropics, with high fecundity and a short lifespan (Garcia, 1998). It is widely distributed in South Asia and Pacific Asia (Chu and So, 1987; King, 2001). The postlarval and adult stages live on the muddy bottoms in estuaries and coastal waters (Holthuis, 1980).

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In the Mekong Delta, *M. ensis* is caught in the brackish waters of rivers and canals, with artisanal fishing gear, including bag nets, cast nets, and trap nets. The bag net is considered the largest scale of these types of artisanal fishing gear.

The commercial value of *M. ensis* is high, not only in Vietnam but in many countries of the world, in response to the high market demand, which is based on the quality of its meat (Liao and Chao, 1983; King, 2001). Various aspects of the species have also been studied in Australia (Courtney et al. 1989), China, Hong Kong (Leung, 1997), and Japan (Taguchi et al. 2002).

However, little information about the species in the Mekong Delta in Vietnam is available. Its basic parameters, such as the frequency of carapace length (*CL),* asymptotic length (L_∞), growth coefficient (*K*), mortality rates (including the fishing mortality coefficient (*F)*, natural mortality coefficient (*M)*, total mortality coefficient (*Z*), and exploitation rate (*E*), have not been adequately studied, although these parameters are very important in fisheries management. These scientific data are used to determine whether an area is overfished or underfished, and allow fisheries managers to develop long-term strategies for a large proportion of the aquatic resources in a region.

Materials and Methods

This study was carried out in the Ganh Hao River, which is the largest river in Bac Lieu Province (9°15′ N, 105°45′ E), located in the coastal region of the Mekong Delta in Vietnam (Fig. 1). The depth and width of the river are shown in Fig. 2; and its transparency is 3.0–10.0 cm (Ministry of Fisheries, 1996). The climate here is tropical, with an average temperature of 29 °C (Hung, 2009). The salinity of the river is 25–30 ppt (Statistical Book of Bac Lieu, 2009). The river is connected to other rivers, creating a network system in the coastal region.
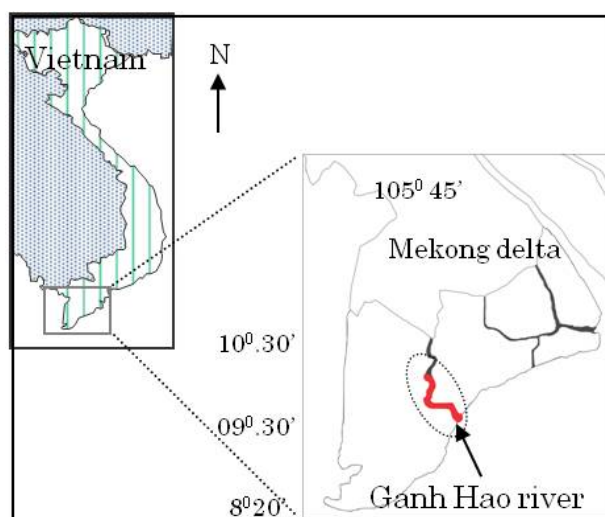

Fig. 1. Maps of Vietnam and the Mekong Delta, showing the study site (red) on the Ganh Hao River.
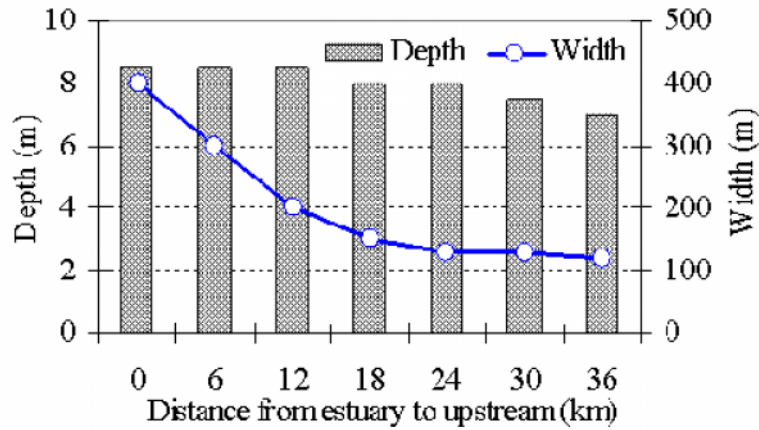
Fig. 2. Width and depth (m) of the Ganh Hao River.

The bag net is the fishing equipment used locally, and is designed to be fixed at a designated site. It is supported by two columns (Fig. 3). The structure of each bag net is such that the mesh size differs in different parts of the net body; the mesh size is largest at the mouth of the bag net (2a = 3.5 cm) and gradually decreases to the end of the net (3.0 cm to 2.5 cm to 2.0 cm), where the mesh size is 1.5 cm. The gradient in mesh size extends for 7–8 m of the net. The total length of the bag net is 26.5–32.0 m, and the net mouth is 5.5–6.0 m high and 10–11 m wide (Fig. 3).

The net is always set in places with currents, such as rivers and canals, and operates on the ebb tide, as the water moves downstream. The principle of the bag net is that the net is set facing the tidal current, so that the shrimp and other aquatic animals are caught as they flow into it on the current. The tide changes direction twice in every 24 hr (day and night) and the time of the tidal change differs daily throughout the month. The bag net is normally operated for 3–4 hr at a time.
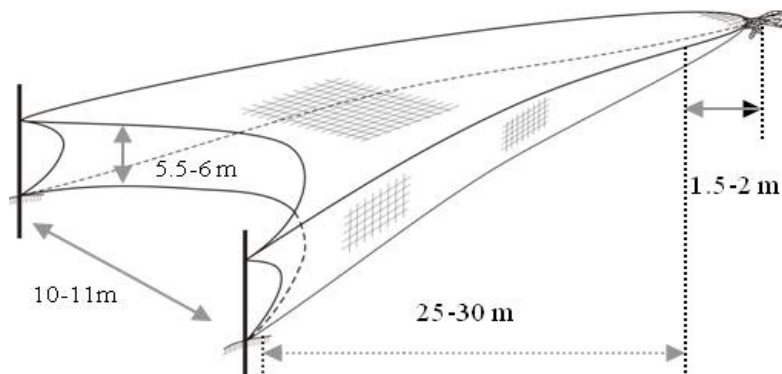

Fig. 3. The bag net, the equipment used in this study.

Six sampling stations were selected on a 30 km stretch of the Ganh Hao River. The samples were collected directly from the bag nets. The first station was in the estuary (0 km), and the other sites extended upstream for 30 km at locations 6 km, 12 km, 18 km, 24 km, and 30 km from the

estuary along the river. The study was performed over 12 months, with six sampling occasions: February, April, June, August, October, and December in 2010.

The samples were kept on ice and measured in the laboratory. The parameters measured were the carapace length *(CL),* measured with calipers as the shortest distance between the posterior margin of the orbit and the mid-dorsal posterior edge of the carapace, to the nearest 0.1 mm; and body weight *(BW),* measured with an electronic balance to within 0.01 g. Furthermore, 10% of the largest individual shrimps collected on each sampling occasion were selected to check the stage of maturity (Dineshbabu et al. 2008). The fecundity of the mature females was estimated from the relationship between the ovary weight and *CL* (Courtney et al. 1989).

The FAO-ICLARM Stock Assessment Tool (Gayanilo et al. 2005) was used to determine the necessary parameters, and ELEFAN 1 was used to identify the optimal growth curve through the maximum peak. *K* and L_∞ were estimated with von Bertalanffy's growth equation:

$$L_t = L_\infty (1 - \exp^{-[k(t - t_0) + St_s + St_0]})$$

$$\text{where } St_s = \frac{CK}{2\pi} \sin(2\pi(t - t_s)); \text{ and } St_0 = \frac{CK}{2\pi} \sin(2\pi(t_0 - t_s)).$$

L_t is *CL* (mm) at age *t* (years); L_∞ is the theoretical maximum (asymptotic length) *CL* mm that *M. ensis* would reach if it lived indefinitely (King, 2001; Gayanilo et al. 2005); *K* is the growth coefficient (year^{-1}); *C* is the amplitude of the seasonal oscillation; *t* is the age (years); t_0 is the age of the shrimp at zero length (years); and t_s is the starting time of the sinusoidal growth oscillation. This study was performed in a tropical region, so the temperature did not oscillate monthly throughout the year.

The total mortality coefficient (*Z*) was required to extrapolate the probability of capture from the length-converted catch curve (Pauly, 1984). Total mortality was based on the *CL* composition calculated from the bag net samples. We assumed that these bag nets are representative of all the bag nets used in the region. The instantaneous value of the fishing mortality coefficient (*F*) was calculated from the estimates for *M* and *Z: F = Z – M.*

The natural mortality coefficient (*M*) was calculated with Pauly's empirical estimate, using a multiple regression model (Pauly, 1982):

$$\log_{10}M = -0.007 - 0.279\log_{10}L_\infty + 0.654\log_{10}K + 0.463\log_{10}T$$

where *T* is the average water temperature. *E*max is the exploitation level that maximizes yield per recruit (Gayanilo et al. 2005).

Longevity is the maximum lifespan of *M. ensis* in the wild, calculated as:

$$T_{max} = t_0 - (l/k)\ln[1-(L_i/L_\infty)],$$

where L_i is the carapace length equal to 99% of the asymptotic length and $t_0 = 0$, or approximately $T_{max} = 3/K$ (King, 2001).

The recruitment pattern of the stock was determined by backward projection on the length axis of the set of available data, as described in FiSAT. This procedure reconstructs the recruitment pulses from a time series of length–frequency data, to determine the number of pulses per year (Gayanilo et al. 2005).

In practice, the biological characteristic of *M. ensis* dictates that it grows in the coastal region, where the water is shallow and the salinity low, but the shrimp migrates to the open sea to reproduce when it reaches the pre-mature and mature stages (Courtney et al. 1989; Garcia, 1998).   If we assume that *M. ensis* starts to migrate when *CL* reaches 30 mm and that the migration index of *M. ensis* is   , migration is considered to affect F_α, E_α, and $E\max_\alpha$ when $0 < \alpha < 1$.

If α is close to 0, there is less migration from the estuary, whereas if α is close to 1, the rate of migration from the estuary is high.

$$C_{CL} = \frac{F_\alpha}{Z_\alpha}(1-e^{-Z_\alpha})N_{CL}(1-\alpha)$$

$\alpha = 0$, when $0 < CL \le 30$;
$\alpha \ne 0$, when $CL > 30$ ($= 0.1–0.9$)

Exploitation rate $E_\alpha = \dfrac{F_\alpha}{Z_\alpha}$

Migrated and observed assessments will be based on the value of α. *M* is assumed to be constant for males and females and this value is not affected by α, whereas a different value of $E\max_\alpha$ corresponds to each value of α.

The length-converted catch curve was used to analyze the probability of capture for each length class, according to Pauly (1987), by plotting the cumulative probability of capture against the mid-length. The length at first capture (*Lc*) corresponded to the cumulative probability at 50%.

Results

The ranges of *CL* were 14.5–33.5 mm for males and 14.5–35.5 mm for females (Fig. 4). Small individuals were abundant from October to February, whereas larger (30 mm) *CL* individuals were not found in October and December. The growth parameters were $L_\infty = 35.2$ mm and 37.3 mm (*CL*) for males and females, respectively, and $K = 1.6$ year^{-1} and 1.5 year^{-1}, respectively.
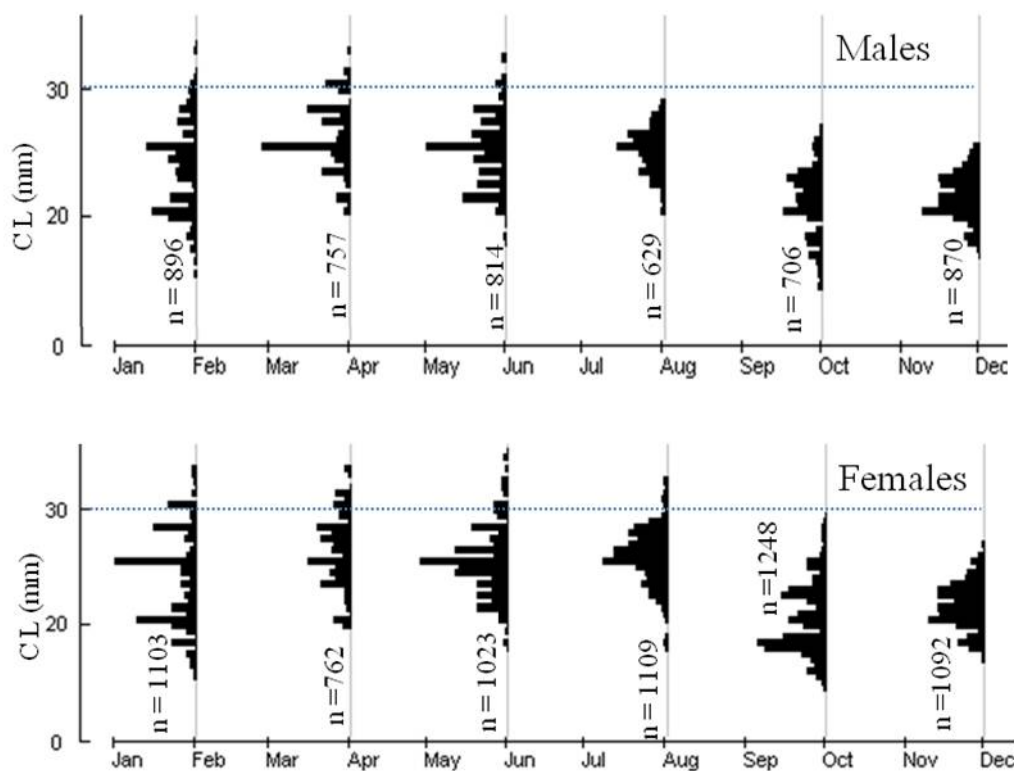

Fig. 4. Frequencies of *CL* (mm) classes for male and female *M. ensis* at the six sampling times in the Ganh Hao River.

Initially, the ascending data points were not included in the regression (Fig. 5), because these points represent the younger age groups, which are subject to lower fishing mortality because they are either not fully recruited or not fully vulnerable to the fishing equipment used. Only a proportion of each younger age class may have moved from the nursery areas and been recruited into the adult stock in the fishing grounds. Some juveniles may also have reached the fishing ground, but they would have been small enough to escape through the mesh of the bag net.
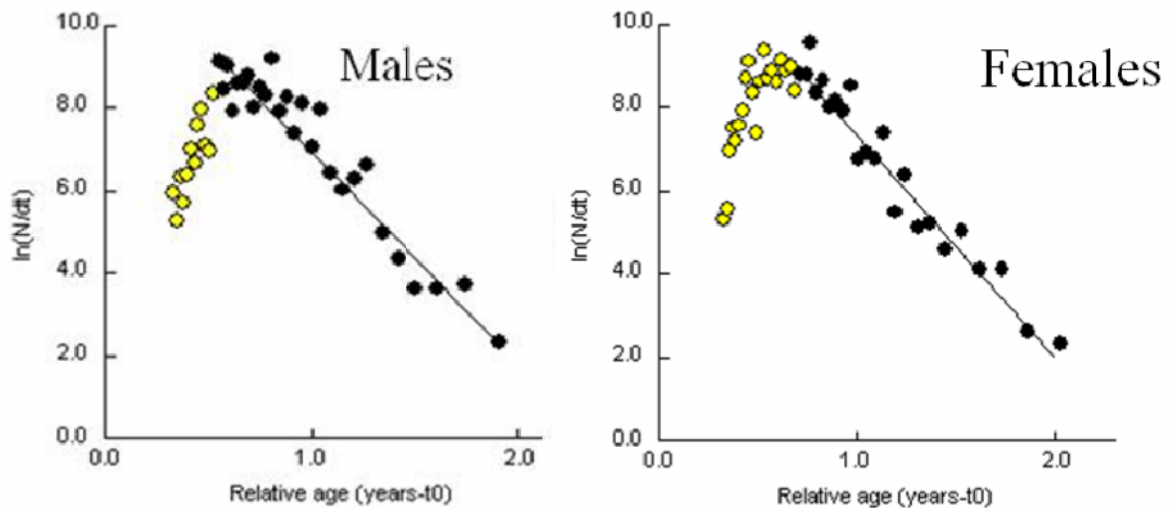
Fig. 5. *CL*-converted catch for *M. ensis* in the Ganh Hao River: $Z_{\alpha=0} = 5.0$, r = –0.96 for males, and $Z_{\alpha=0} = 4.9$, r = –0.94 for females. The dark dots represent the points used to calculate the least squares linear regression and the open dots represent the points either no fully recruited or nearing L_∞: n = 27, *Y* = 12.1 – 5.0*X*, 95% confidence interval: 11.4–12.7, slope (b) = –5.0 for males; and *n* = 23, *Y* = 12.8 – 5.3*X*, 95% confidence interval: 12.1–13.5, slope (b) = –5.3 for females.

The longevity estimated for *M. ensis* was = 1.8 years for males and 2 years for females, with *M* = 2.3 year^{-1} and 1.7 year^{-1} for males and females, respectively.

The recruitment pattern of *M. ensis* is shown in Fig. 6, with two peaks per year in April–May (16%–24%) and July–August (8.4%–10%). However, recruitment was continuous between these peaks, with the lowest values in December–February.
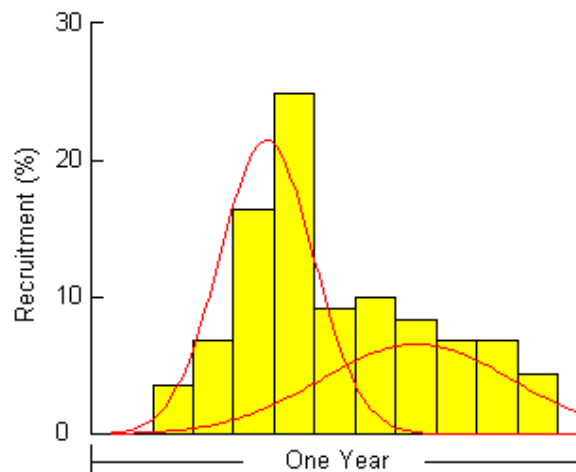

Fig. 6. Recruitment pattern of *M. ensis* in the Ganh Hao River.

In other words, *M. ensis* in the Mekong Delta starts migrating offshore to spawn in October–December, and the postlarvae and juvenile fish enter the fishing ground, estuary and coastline to grow in April/May–July/August to complete their life cycles.

Each value of α corresponded to a different value of E_α and $E\max_\alpha$, and the relationships between these values are shown in Fig. 7, which also shows the negative correlation between α and E_α or $E\max_\alpha$. However, $E_\alpha < E\max_\alpha$ for males and females for any value of α, which means that *M. ensis* is under-fished in the region.
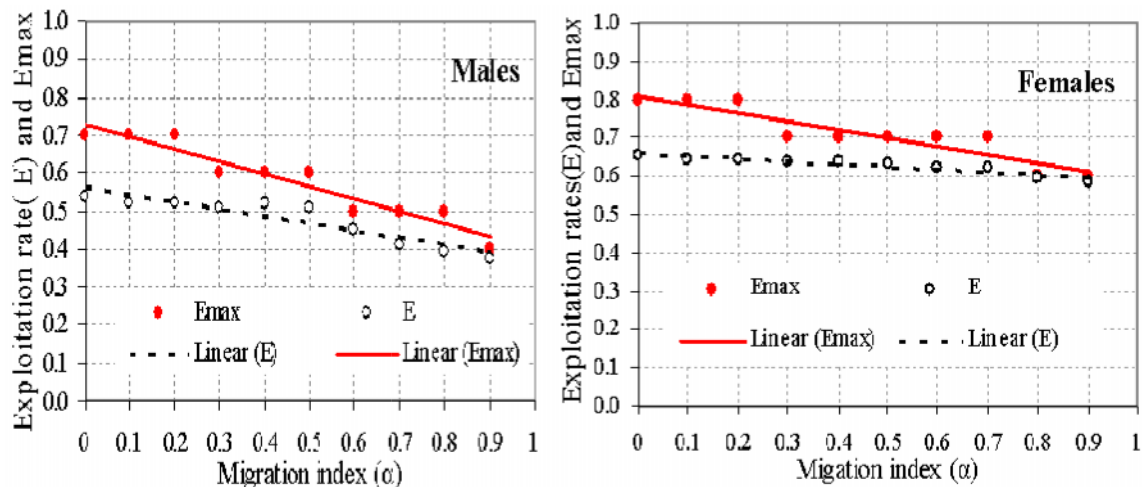

Fig. 7. Relative migration rates and exploitation rates (E_α and $E\max_\alpha$) for males and females.

The probability of capture was identified from *CL* (mm) at first capture, as the length at which 50% of the shrimp becomes vulnerable to the gear. This was calculated as a component of the length-converted catch curve: L_c or $L_{50\%}$ was 20.1 mm for males and 20.5 mm for females (Fig. 8).
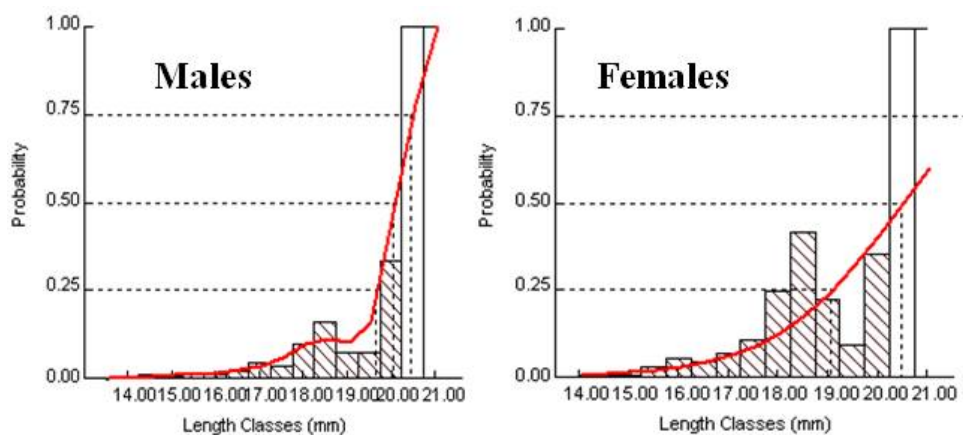

Fig. 8. Probability of first capture of *M. ensis* $L_{50\%}$ = 20.1 mm for males and 20.5 mm for females.

We also found that the region is open access for the whole year, and that a high proportion of the shrimp caught are small (Fig. 9), which could have a negative impact on the aquatic resources in the future.
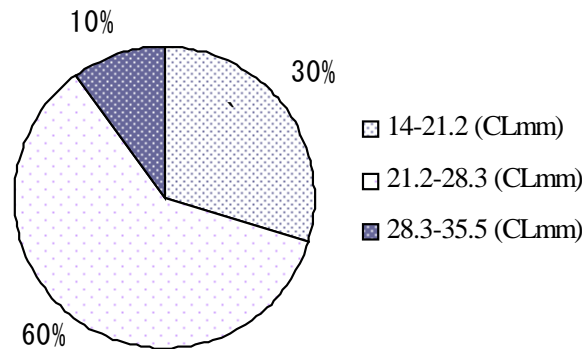

Fig. 9. Proportions of shrimp (*M. ensis*) size classes in the Ganh Hao River.

Discussion

The fishing activities of fishermen were carried out throughout the year, and the frequencies of the different *CL* classes differed in various months, which supports the concept of several recruitments per year (Fig. 4). The *CL* of *M. ensis* fluctuated greatly between the rainy and dry seasons. However, it was not clear in which months *CL* peaked in each season, confirming that this species can spawn throughout the whole year. However, the seasonal reproduction of the penaeid shrimp is a very complex issue, because it is affected by varying environmental factors, including rainfall, temperature, and water depth (Dall et al. 1990). Therefore, its seasonal reproduction can differ across different regions. A study in Australia also found that *M. ensis* spawns throughout the year, with the highest peak from September to November and the lowest peak between January and February (Crocos et al. 2001).

The recruitment pattern of *M. ensis* is also a complex issue, because recruitment occurs in different months in various regions. It was observed in April–May and July–August in the Mekong Delta, but the peaks shown in Fig. 6 are continuous. The recruitment of the penaeid shrimps is also related to the lunar cycle (Garcia, 1998). A study in Hong Kong found that new recruits began to enter the catch region in April–May, where they grew during June–August, and that this was followed by another smaller recruitment in October (Cheung, 1964). However, the peak recruitment of *M. ensis* occurred in April–June and September–October in Hong Kong (Leung, 1997). A study in the Gulf of Mexico found that the spawning peaks for Penaeidae shrimp occurred in May–June and August–September (Neal and Maris, 1985). The recruitment of postlarvae tended to follow a 28 day cycle, with increased immigration on alternate spring tides (Staples and Vance, 1987). New recruits (2–3 mm *CL*) migrated into the estuaries of southwestern Australia between December and April (Potter and Manning, 1991).

Habitat is also a factor that affects the migration of postlarval shrimp during the recruitment of *M. ensis*, influencing shrimp abundance in coastal regions (Neal and Maris, 1985; King, 2001). Negative impacts on the shrimp habitats have been recorded in the study region, where mangrove areas are being reduced and coastline pollution is increasing, and these problems have affected shrimp recruitment and the development of local natural resources (Johnston et al. 2000).

Metapenaeus ensis is now underexploited in terms of the relative yield per recruit in the Ganh Hao River, according to our analysis of the exploitation rate (E_α) based on mortality estimates. This indicates that the fishery is functioning below the optimum level ($E\max_\alpha$). Therefore, the fishing pressure on the stock is not excessive when $\alpha = 0.0$–0.9 and a greater yield could be achieved with a reasonable increase in the fishing effort. The bag net is a passive apparatus that obstructs the current and filters the shrimp from the water, so the shrimp are less vulnerable to it than to active equipment, such as trawl nets, which actually pursue the shrimp.

However, because the bag net is considered a destructive aquatic resource by fisheries managers, the resource is now underexploited ($E_\alpha < E\max_\alpha$). However, there is a high risk of overfishing *M. ensis* because F_α is approximately 1.4–1.9 times greater than M when $\alpha = 0.9 \sim 0.0$, which means that *M. ensis* is captured as by-catch, with a high proportion of small shrimp. This does not augur well for the status of fishing in the region. In practice, the bag net can catch small and weak individuals that move beneath the current, resulting in a waste of aquatic resources, which will negatively affect the aquatic resources.

Mature individuals were not collected during the study for two main reasons. First, large individuals are more able avoid the gear (bag net) by a rapid swimming reaction, which may ensure that that larger *M. ensis* are caught less often in the bag net than small shrimp. Second, the environmental conditions in the region are not sufficiently consistent to ensure a homogeneous distribution of mature individuals, because the salinity is low (Leung, 1997). A study of the Pearl River found that immature shrimp are most abundant from February to October in response to low salinity (Cheung, 1964), and mature females were found at depths of 15–30 m, salinity > 33 ppt, and temperatures of 26–30 °C (Crocos et al. 2001). Therefore, mature individuals could not be found in the study area.

The longevity of the penaeid shrimp is often affected by different types of fishing gear and environmental factors. In this study, shrimp longevity was 1.8 years for males and 2 years for females, whereas the lifespan of this species is 15–20 months in Hong Kong (Cheung, 1964), although the longevity of the penaeid shrimp has been reported to be 2–3 years (Garcia, 1985). Leung (1997) found that the lifespan of *M. ensis* was 14–16 months in Hong Kong, shorter than their physiological longevity, because of environmental variables and fishing pressure. However, the total lifespan of the Penaeidae shrimp is usually less than 2 years (Dall et al. 1990). Predators and

environmental factors are important factors affecting the longevity of these shrimps (Niamaimandi et al. 2007).

Increasing the fishing pressure can affect the marketable size of the shrimp, and when a high proportion of small shrimp are caught, it is clear that the species is being exploited at various stages of its life cycle (Garcia, 1998). It is directly used for commercial purposes with larger size, for coastal aquaculture with postlarvae and juveniles (Kungvankij and Chua, 1986). Fischer and Bianchi (1984) found that the mean value for *CL* in *M. ensis* is 35 – 45 mm and the maximum *TL* is 154–189 mm. However, it has also been reported that the maximum *TL* is often between 70 and 140 mm and the approximate *CL* is 17–37 mm (Garcia, 1985). Although in this study the maximum *CL* was 33.5 mm and 35.5 mm for males and females, respectively, these large individuals constituted a small proportion of the catch (Fig. 10).
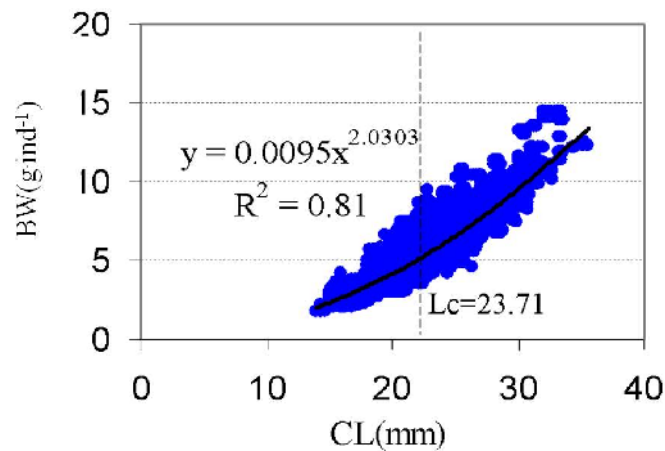

Fig. 10. Relationship between *CL* and *BW* of *M. ensis* in the Ganh Hao River.

The livelihoods of local residents can be directly affected when small individual shrimp are caught in the region, because it causes the resource to decline. The price of *M. ensis* depends on its size in the Mekong Delta, and when *BW* is greater than 10 g$^.$individual^{-1}, the price is US\$5.0–5.5 per kg (in 2010). However, the average *BW* in this study was 6.0±2.2 g$^.$ individual^{-1}, corresponding to a price of US\$3–4 per kg. Increasing the mesh size of the net is a possible solution to the preponderance of small individual shrimp and by-catch (postlarvae, juveniles) during commercial fishing. When high proportions of small individuals are caught, the sustainable development of the aquatic fisheries in the region will be compromised (Ministry of Fisheries, 2006). Although *M. ensis* is now underfished, fisheries managers must establish new regulations for the mesh size of the nets, not only to ensure that fishermen can catch larger individual of greater value, but also to enhance the development of the aquatic resource in a large area of the region. This will form part of the long-term strategy for the sustainable development of aquatic fisheries in the region in the future.

Conclusion

Both males and females of the greasyback shrimp, *M. ensis*, in the Ganh Hao River are underexploited ($E_\alpha < E \max_\alpha$). However, there is a high risk of overfishing *M. ensis* because F_α is approximately 1.4–1.9 times greater than *M* when $\alpha = 0.9{\sim}0.0$. *Metapenaeus ensis* is captured as by-catch, with a high proportion of small shrimp. Although *M. ensis* is now underfished, fisheries managers must establish new regulations for the mesh size of the nets, not only to ensure that fishermen can catch larger individuals of greater value, but also to enhance the development of the aquatic resource in a large area of the region.

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