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The role of greasyback shrimp (*Metapenaeus ensis*) in improved extensive shrimp farming systems in the Mekong Delta, Vietnam

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Abstract: In 2010, a variety of factors affecting the size and yield of *Metapenaeus ensis* were measured on shrimp farms in the My Xuyen (MX) and Dong Hai (DH) Districts, Mekong Delta, Vietnam. Studies were conducted in shrimp-rice paddy rotation systems (in MX) and in integrated shrimp-mangrove systems (in DH). A survey was conducted in 120 households, and samples were obtained from a total of 8 farms in the 2 districts. Results showed that *M. ensis* seed was collected from wild populations through tidal recruitment at sluice gates. The recruitment occurred multiple times per year. Yields of *M. ensis* in MX and DH were 31.0±5.9 kg • ha^{-1} • $year^{-1}$ and 39.2±4.7 kg • ha^{-1} • $year^{-1}$, respectively. The yields were positively correlated with the frequency of water exchange and with the depths of ditches and flat-forms ($p<0.01$). The contributions of *M. ensis* to the total shrimp yield in MX and DH were 6.0% and 12.2%, respectively, with respect to yield, and 8.5% and 7.3%, respectively, with respect to value.

Keywords: *Greasyback shrimp, Metapenaeus ensis, shrimp-rice paddy rotation systems, integrated shrimp-mangrove systems*

1. Introduction

Shrimp farming plays an important role in the societal and economic development of coastal communities in Vietnam (JOHNSTON *et al.*, 2000a; SINH, 2009). The area devoted to shrimp cultivation expanded from 90,000 ha in 1991 to 430,000 ha in 2003 (LOC, 2003), and the yield increased from 55,316 tons in 1995 to 413,132 tons in 2009 (ANONYMOUS, 2010a). Shrimp export values in 2007 were over US$ 1.2 billion (TU *et al.*, 2008).

In Vietnam, reported shrimp yields are mainly for the black tiger shrimp (*Penaeus monodon*), because this is the only species for which fishery managers have collected data and conducted annual assessments. The species has been studied by authors from both Vietnam and abroad from many viewpoints, such as fishery techniques, market factors, and societal and economic development. However, *P. monodon* is not the sole commercial shrimp species in Vietnam. Many other high-value species (e.g., *Metapenaeus ensis*, *Metapenaeus lysianassa*, and *Penaeus merguiensis*) are also harvested on shrimp farms. The seed sources for these (non-*P. monodon*) species are wild populations, referred to as “natural shrimp,” collected by tidal recruitment (JOHNSTON *et al.*, 2000b). In contrast, artificial seed has been used in *P. monodon* since 1990 (NHUONG and HA, 2005).

The Mekong Delta (MD) in the southern region of Vietnam, with an area of about 39,000 km^2, contains 70% of the nation’s shrimp farming. A variety of farming systems are used in this region.

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In traditional extensive shrimp farming systems, the wild seed is trapped and held until harvest. Stocking densities are low, food supplements are not provided, and there is no fertilization (BRENAN *et al.*, 2006). In improved extensive shrimp farming systems, the traditional system is modified by supplementation with artificial stocks of *P. monodon* (stocking density, 1－7 individuals・m^{-2}), either with or without feeding (PHUONG *et al.*, 2006; ANONYMOUS, 2007). Finally, in semi-intensive and intensive systems, which have steadily expanded since 2000 (VIET, 2006), *P. monodon* is cultured using intensive food and habitat enrichment schemes to produce rich harvests.

Metapenaeus ensis, which is caught and cultured as part of the traditional shrimp farming activities of local residents in Southeast Asia (LING, 1973), tolerates a wide range of salinity (5－30) and is in high local market demand because of its high meat quality (LIAO and CHAO, 1983; KING, 2001). In the Gulf of Carpentaria, Australia, the maximum total length is 154 mm for males and 189 mm for females (GARCIA, 1985). The longevity of *M. ensis* is approximately 14 months, as found in Hong Kong, China (LEUNG, 1991). Various aspects of this species have been investigated in different countries, such as its reproductive biology in Australia (COURTNEY *et al.*, 1989), its population dynamics in a shrimp pond in Hong Kong (LEUNG, 1997), and the modeling of population dynamics in Osaka Bay, Japan (TAGUCHI *et al.*, 2002).

In this study, we focused on the status of *M. ensis* in improved extensive shrimp farming systems in Vietnam. These systems constitute about 75% of the total shrimp farming area in MD. The results of this study contribute to the development of a critically needed database on resources vital to the socioeconomic well-being of populations in Southeast Asia, especially in the MD area.

2. Materials and Methods

2.1. Study sites

This study was conducted in 2010 in the My Xuyen (MX) district of Soc Trang Province and in the Dong Hai (DH) district of Bac Lieu Province in the MD (Fig.1). These locations are

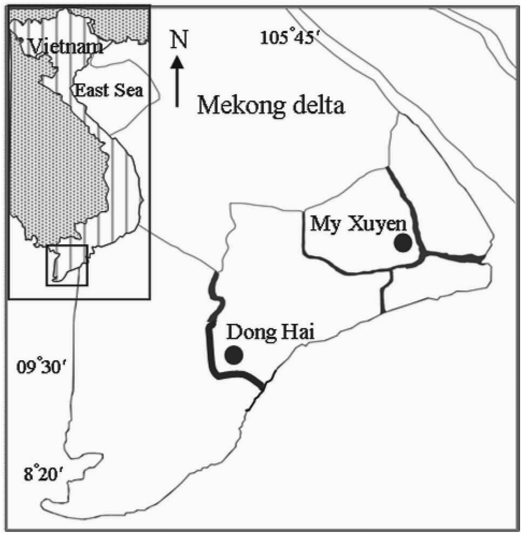

Fig. 1. Location map of Vietnam, the Mekong Delta, and sampling sites in the My Xuyen (MX) and Dong Hai (DH) Districts.

representative of the social, economic, and environmental characteristics of the MD region. MD, with its tropical climate, is biseasonal with a rainy season from June to November and a dry season from December to May (HUNG, 2009). An estimated 19% (786,329ha) of the total area is affected by changing water salinity, with predominately fresh water in the rainy season and brackish water in the dry season (VUONG and LIN, 2001). The most important locations for improved extensive shrimp farming systems are (1) in rice paddies by using shrimp-rice crop rotation and (2) in integrated shrimp-mangrove habitats.

The shrimp-rice paddy rotation system, which was introduced 30－40years ago (VUONG and LIN, 2001; PRESTON *et al.*, 2003), consists of rice cultivation in the wet season (on flat-form areas in predominately fresh-water conditions) and shrimp culturing in the dry season (in predominately saline-water conditions) (BRENNAN *et al.*, 2002). Rice is cultivated from June/July to September/October, when salinity is 0－3, while shrimp are cultured from January/March to May/June, when salinity is greater than 3.

The total land area of the MX district is

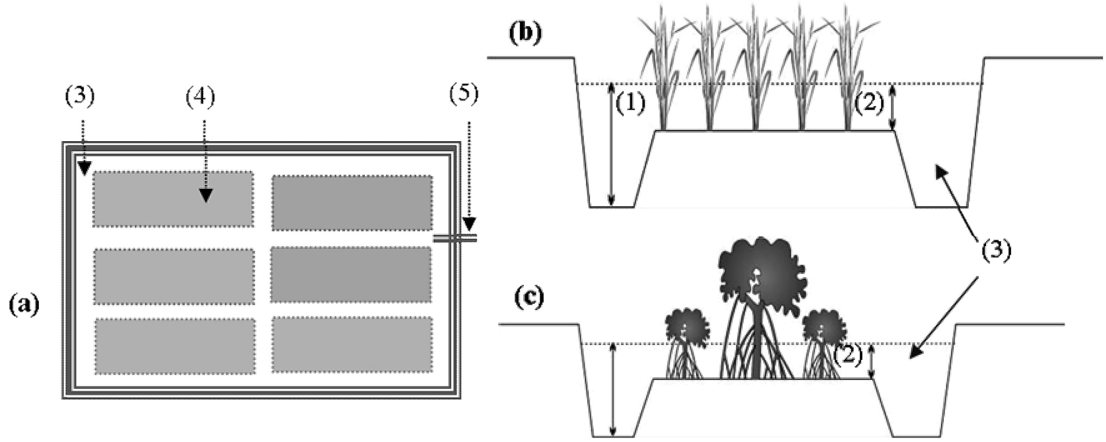

Fig. 2. Construction of farms in the My Xuyen and Dong Hai Districts, designed for improved extensive shrimp culture farming. (a) Relative proportions of ditch and flat-form areas; (b) and (c) Transects of a shrimp-rice paddy rotation system and an integrated shrimp-mangrove system located in MX and DH, respectively, showing (1) ditch depth; (2) depth of flat-form; (3) ditch; (4) flat-form; and (5) sluice gate.

54,450ha (ANONYMOUS, 2010b). The area of shrimp-rice paddy rotation increased from 500ha in 1982 to 6,635ha in 1988 (PRESTON *et al.,* 2003) and to 20,200ha in 2010 (ANONYMOUS, 2011a). Combined shrimp-rice farming provides enhanced income and economic benefits to farmers, as compared with that provided by the cultivation of either shrimp or rice alone (VUONG and LIN, 2001). Mangrove forests occupy 52,786ha in the DH district (ANONYMOUS, 2010c), in regions where salinity ranges from 28 to 34 (ANONYMOUS, 2010d). Shrimp-mangrove farms are designed so that mangrove trees occupy flat-form areas and shrimp are cultured throughout the year. The operational principles of this system are described by BINH *et al.* (1997) and JOHNSTON *et al.* (2000a). The design of these farms is shown in Fig. 2.

2.2. Data collection

Information was collected in a survey of 60 households from each district, it contains farming area, depth of flat-form and ditch, frequency of water change, yields and prices of *M. ensis* and *P. monodon* and other shrimps, investment and income. The participants were farmers who were applying the improved extensive system in these districts.

Table 1. Areas and abbreviations of farms in the two districts where samples were collected.

My Xuyen		Dong Hai	
Farm	Area (ha)	Farm	Area (ha)
AMX	1	ADH	4.3
BMX	1.5	BDH	2.5
CMX	1	CDH	3
DMX	0.6	DDH	3.4
Mean ± SD	1.03 ± 0.4	Mean ± SD	3.3 ± 0.8

Shrimp sampling was conducted at a total of 8 farms in the MX and DH districts (4 farms in each district). Table 1 shows the area of each farm. The distance between farms in both districts was about 0.2 km. Shrimp culturing/harvesting in MX occurs only during the dry season; therefore, sampling was conducted only between January and June. *Metapenaeus ensis* in MX farms was collected at night by using trap nets, as shown in Fig. 3 (a), with a mesh size of 1.5 − 1.7 cm. The trap nets were submerged in the ditch, as shown in Fig. 2 (b−3). Sampling was performed on 2 nights, for approximately 8h each night (9 : 00PM to 5 : 00 AM), by using 6 trap nets at each farm during each sampling time.

In contrast, shrimp culturing in DH occurs

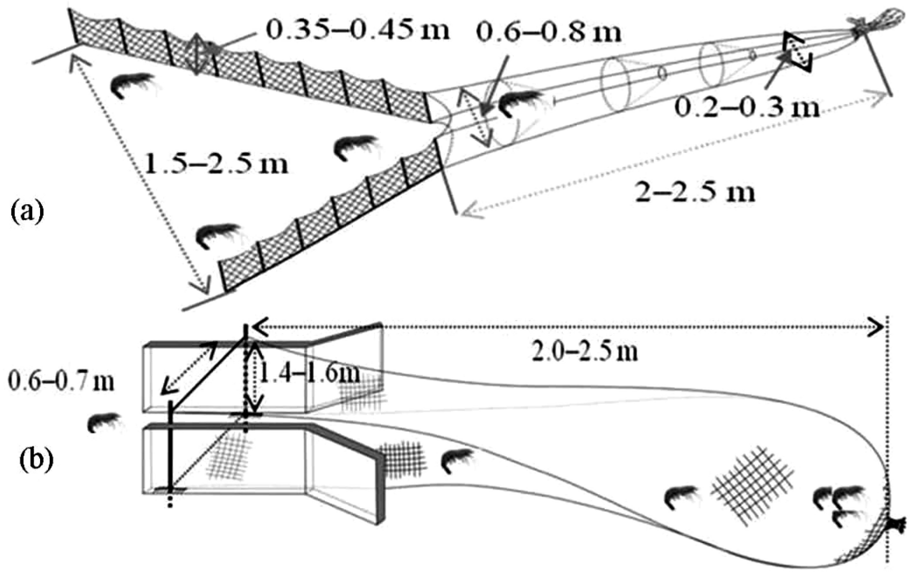

Fig. 3. Trap net design used to catch shrimp in ditches (a) and sluice gates (b).

throughout the year, and sampling was conducted in February, April, June, August, October, and December in 2010. The sampling was conducted during the spring tide of each month, drainage was controlled using a sluice gate, as shown in Fig. 3 (b), through which shrimp were recruited and harvested. *Metapenaeus ensis* was sampled on 2 nights, for 3－4h per night, by using a single sluice gate at each farm.

Shrimp samples collected inside the farms included shrimp obtained via new recruitment and old shrimp from previous recruitments. The samples of *M. ensis* were kept in ice prior to the measurement of carapace length (CL). CL was measured to the nearest millimeter by using calipers and defined as the shortest distance between the posterior margin of the orbit and the mid-dorsal posterior edge of the carapace. In addition, salinity was measured as an important physical characteristic of the water (Macia, 2004).

2.3. Data analysis

The non-parametric Wilcox test was used to test the significance of differences between the observed variables in the 2 districts. Akaike's Information Criterion (AIC) (Akaike, 1973) was used to select the variables that affected the yield, and these variables were used in the multivariate regression models (Dalgaard, 2002; Faraway, 2005).

In this case, the dependent variable, y, is defined as the yield of *M. ensis*, and the maximum number of independent variables, which were defined later, is 6. The number of models, which are constructed using a single independent variable (x_1, x_2, ⋯, or x_6), can be calculated by the combination C(6, 1)=6, i.e., $y=f_1(x_1)$, $y=f_2(x_2)$, ⋯, $y=f_6(x_6)$. The number of models, which are constructed using 2 independent variables (x_1, x_2), (x_1, x_3), ⋯, or (x_5, x_6), can be calculated by the combination C(6, 2)=15, i.e., $y=f_7(x_1, x_2)$, $y=f_8(x_1, x_3)$, ⋯, $y=f_{21}(x_5, x_6)$. The total number of models can be calculated by the summation of the combinations $\sum_{i=1}^{6} C(6, i)=64$. We calculated the AIC values for each of the 64 models and selected the optimal model as the one with the lowest AIC (Faraway, 2005).

When the linear regression equation is expressed as follows :

$$\hat{y} = \hat{\alpha} + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + \cdots + \hat{\beta}_k x_k$$

with $k+1$ parameters ($\hat{\alpha}, \hat{\beta}_1, \hat{\beta}_2, \cdots, \hat{\beta}_k$), and the

Table 2. Parameters of the improved extensive shrimp farming systems in the MX (mainly shrimp –rice paddy rotation systems) and the DH (mainly integrated shrimp–mangrove forest systems) (mean±standard deviation).

Item	My Xuyen (n=60)	Dong Hai (n=60)
Period of shrimp culture ($month \cdot year^{-1}$)	6	12
Farming area ($ha \cdot household^{-1}$)	0.9 ± 0.3^a	1.7 ± 0.6^b
Depth of flat-form (m)	0.5 ± 0.3^a	0.4 ± 0.1^b
Depth of ditch (m)	0.9 ± 0.1^a	0.8 ± 0.1^b
Frequency of water exchange ($times \cdot year^{-1}$)	6.6 ± 1.2^a	19.5 ± 1.8^b
Yield of M. ensis ($kg \cdot ha^{-1} \cdot year^{-1}$)	31.0 ± 5.9^a	39.2 ± 4.7^b
Coefficient of variation of M. ensis yield (CV)(%)	18.9	11.9
Price of M. ensis ($US\$ \cdot kg^{-1}$)	3.4 ± 0.5^a	3.5 ± 0.1^a
Yield of P. monodon ($kg \cdot ha^{-1} \cdot year^{-1}$)	539.5 ± 265.7^a	322.2 ± 91.7^b
CV of P. monodon yield (%)	49.3	28.4
Price of P. monodon ($US\$ \cdot kg^{-1}$)	5.3 ± 0.4^a	6.7 ± 0.7^b
Yield of aquatic other species ($kg \cdot ha^{-1} \cdot year^{-1}$)	$30.5 \pm .5.7^a$	29.2 ± 7.6^a
CV of aquatic other species (%)	18.8	26.0
Price of aquatic other species ($US\$ \cdot kg^{-1}$)	1.7 ± 0.2^a	1.5 ± 0.1^b
Total investment from shrimp ($US\$ \cdot ha^{-1} \cdot year^{-1}$)	861.5 ± 179.7^a	308.5 ± 71.6^b
Net income from shrimp ($US\$ \cdot ha^{-1} \cdot year^{-1}$)	$2{,}380 \pm 1{,}666^a$	$2{,}108 \pm 741.8^b$
CV of income from shrimp (%)	70	35.1
Total cost from rice paddy $US\$ \cdot ha^{-1} \cdot crop^{-1}$)	934 ± 130	0
Net income from rice paddy ($US\$ \cdot ha^{-1} \cdot crop^{-1}$)	645.7 ± 117.6	0
Coefficient of variation of rice paddy (%)	18	Invalid
Total of net income ($US\$ \cdot ha^{-1} \cdot year^{-1}$)	$2{,}444.8 \pm 1{,}650^a$	$2{,}108 \pm 741.8^b$
Total of net income ($US\$ \cdot household^{-1} \cdot year^{-1}$)	$2{,}716.5 \pm 1{,}485^a$	$3{,}584 \pm 1{,}681^b$
CV of net income $household^{-1} year^{-1}$ (%)	54.6	36.3

Mean values of parameters in the same row with the different superscripts show significant different ($p<0.01$)

residual sum of squares is expressed as $RSS = \sum_{i=1}^{n} (\hat{y}_i - y_i)^2$, then AIC is calculated by:

$$AIC = \log\left(\frac{RSS}{n}\right) + \frac{2k}{n}$$

where n is the number of samples.

The density function was used to determine the variations in CL for each sampling time. The CL had a normal distribution; analysis of variation and Tukey's honestly significant difference test were used to test for the significance of CL variations between different months.

To relate these data to characteristics of the shrimp culture system, 8 variables (defined later) were selected from the surveys for analysis. These variables were considered to have effects on the system in terms of the aquaculture (Macia, 2004), and they were hypothesized to have effects on the yield and CL of *M. ensis*. Factor analysis (FA) was used to reduce the original number of variables and identify new variables that explained the most important variances in the data.

3. Results

3.1. Contribution of *M. ensis* to households

The contribution of *M. ensis* to the total shrimp yield in the MX and DH districts in 2009 was 6.0% and 12.2%, respectively, in terms of physical yield, and 8.5% and 7.3%, respectively, in terms of crop value. The yields of

Table 3. Results of factor analysis, based on eight parameters obtained from the survey of 120 households in My Xuyen and Dong Hai. The eight parameters were extracted from Table 2.

	My Xuyen		Dong Hai	
	Factor 1	Factor 2	Factor 1	Factor 2
P. monodon yield ($kg \cdot ha^{-1} \cdot year^{-1}$)	0.9		0.99	
Depth of flat–form (m)			0.77	
Depth of ditch (m)	0.50		0.64	
Net income ($US\$ \cdot ha^{-1} \cdot year^{-1}$)	0.97		0.95	
M. ensis yield ($kg \cdot ha^{-1} \cdot year^{-1}$)		0.87		0.94
Frequency of water exchange ($times \cdot year^{-1}$)		0.70		0.79
Yield of other species ($kg \cdot ha^{-1} \cdot year^{-1}$)				
Total cost of shrimp production ($US\$ \cdot ha^{-1} \cdot year^{-1}$)				
Coefficient of determination	0.26	0.16	0.37	0.21
Total coefficient of determination		0.42		0.58

M. ensis were found to be more stable than those of *P. monodon*. The coefficients of variation for *M. ensis* yields were 18.9% and 11.9% in the MX and DH districts, respectively, while those for *P. monodon* yields in the 2 districts were 49.3% and 28.4%, respectively (Table 2).

According to farmers in MX, the main purpose of food supplements is to feed *P. monodon,* because this species is stocked at a density of 5−6 individuals • m^{-2}. In contrast, in DH the land area per household is larger than the land area of MX households ($p<0.01$) (Table 2), and *P. monodon* is stocked at lower densities (1−3 individuals • m^{-2}) 3−5 times per year. This pattern of stocking is referred to as thinning (by harvesting) and subsequent stock compensation, enabling shrimp farms to maintain a low density of individuals without food supplements.

The total investment for shrimp culturing in MX was higher than that in DH ($p<0.01$). However, the situation reversed with respect to the net income from shrimp culturing in the 2 districts, which was significantly different ($p<0.01$) (Table 2). However, farmers in MX also obtain an income from rice paddy harvests in the rainy season (Table 2) ; therefore, their income per hectare is actually higher than that of the DH residents. While DH is located in the ecological mangrove region, the region can not grow rice paddy. Besides, shrimp culture activities of farmers in the region are used depending much on natural environment, low investment and low yield, farming area of each household in DH is larger area than in MX, thus, their income per household are higher than in MX (Table 2).

FA was used to identify 2 orthogonal linear combinations of the 8 original parameters measured in MX (Table 3). These 2 factors are shown in Fig.4 (a). Factor 1 has 3 components, representing a positive correlation between the depth of the ditch and the yield of *P. monodon* and net income. Factor2 has 2 components, representing a positive correlation with the number of water exchanges and the yield of *M. ensis.* These factors explained 42% of the original variance; factors 1 and 2 explained 26% and 16%, respectively, of the variance in the data.

Similarly, the first 2 factors of the FA in DH explain 58% of the variance in the 8 original parameters measured in DH (Table 3). These factors (Fig. 4 (b)) showed that factor 1 has 4 components, representing a positive correlation among the yield of *P. monodon*, the depth of the flat-form, the depth of the ditch, and the net household income. Factor2 has 2 components, representing the yield of *M. ensis* and the number of water exchanges. Factors 1 and 2 explained 37% and 21%, respectively, of the variance in the DH data.

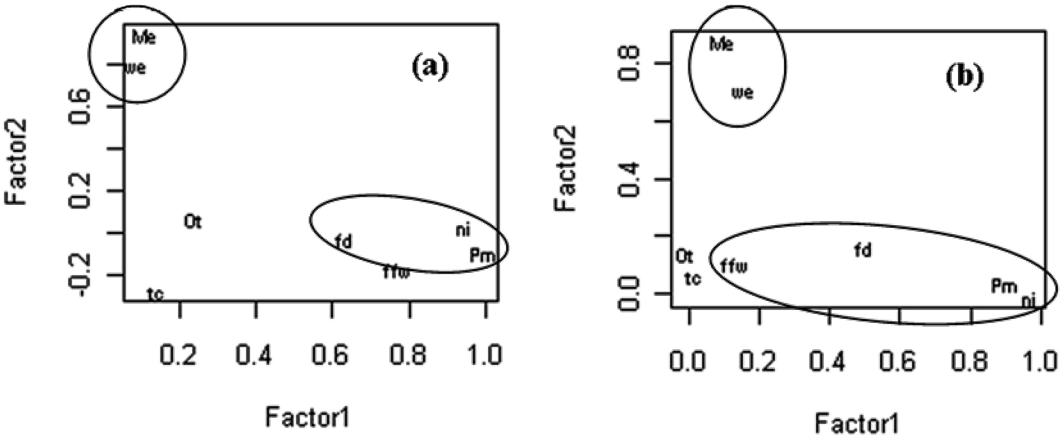

Fig. 4. Plot of the first 2 factor analysis loading vectors for My Xuyen (a) and Dong Hai (b). Me : *M. ensis* yield; we : number of water exchanges; Ot : yield of other species; fd : depth of ditch; ffw : depth of flat-form; tc : total cost; ni : net income; and Pm : *P. monodon* yield.

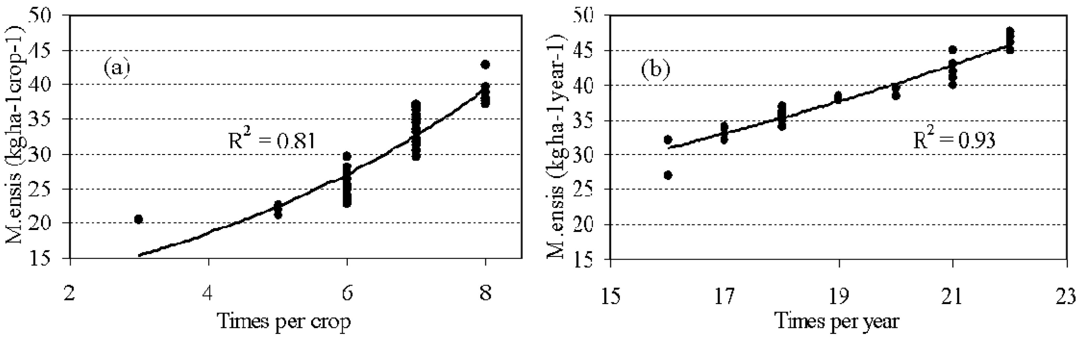

Fig. 5. Correlation between frequecies of water exchange and *M. ensis* yields in My Xuyen (a) and Dong Hai (b).

3.2. Variables affecting the yield of *M. ensis*

Farmers in MX often add more water to their farms to compensate for leakage or evaporation, and they limit the drainage of water away from farms because brackish water is scarce and the quality is variable. We found that the number of water exchanges in DH was higher than that in MX ($p<0.01$; Table 2) and that yields of *M. ensis* were positively correlated with the number of water exchanges (Fig. 5).

Ditches and flat-forms were deeper in MX than in DH ($p<0.01$). Results of the multivariate regression analysis were as follows. When 6 independent variables ($x_{1sr}, x_{2sr}, x_{3sr}, x_{4sr}, x_{5sr}$, and x_{6sr}) were used, the model explained 46% of the variance in the yield of *M. ensis*, where $x_{1sr}, x_{2sr}, x_{3sr}, x_{4sr}, x_{5sr}$, and x_{6sr} denote the rate of water exchange, depth of ditch, depth of flat-form, yield of other species, yield of *P. monodon*, and price of *P. monodon*, respectively. The number of water exchanges (x_{1sr}) was significant in all the cases; this variable is a significant predictor of *M. ensis* yields ($p<0.01$). The optimal model that minimized the AIC value (AIC=184, R^2 =0.45) was as follows :

$$y_{sr}=3.6+3.18\,x_{1sr}+0.96\,x_{2sr}+11.35\,x_{3sr} \quad (1)$$

Table 4. Predictions for optimal yields of *M. ensis* in the My Xuyen (MX) and Dong Hai (DH) districts with multivariate regression models. Subscriptions of *sr* and *sm* denote the shrimp rice in MX and shrimp mangrove in DH, respectively. *y* denotes the *M. ensis* yield. x_1, x_2, x_3, x_4, x_5, and x_6 denote the frequency of water exchange, depth of ditch, depth of flat-form, yield of other species, yield of P. monodon, and quantity of *P. monodon* stocked, respectively.

MX (N=60)			DH (N=60)		
Model	AIC	R^2	Model	AIC	R^2
$y_{sr}=f\ (x_{1sr}, x_{2sr}, x_{3sr}, x_{4sr}, x_{5sr}, x_{6sr})$	188	0.46	$y_{sm}=f\ (x_{1sm}, x_{2sm}, x_{3sm}, x_{4sm}, x_{5sm}, x_{6sm})$	144	0.59
$y_{sr}=f\ (x_{1sr}, x_{2sr}, x_{3sr}, x_{4sr}, x_{5sr})$	186	0.46	$y_{sm}=f\ (x_{1sm}, x_{2sm}, x_{3sm}, x_{4sm}, x_{5sm})$	143	0.58
$y_{sr}=f\ (x_{1sr}, x_{2sr}, x_{3sr}, x_{4sr})$	185	0.46	$y_{sm}=f\ (x_{1sm}, x_{2sm}, x_{3sm}, x_{4sm})$	141	0.58
$y_{sr}=f\ (x_{1sr}, x_{2sr}, x_{3sr})$	184	0.45	$y_{sm}=f\ (x_{1sm}, x_{2sm}, x_{3sm})$	140	0.57
			$y_{sm}=f\ (x_{1sm}, x_{2sm})$	139	0.56
			$y_{sm}=f\ (x_{1sm})$	138	0.56

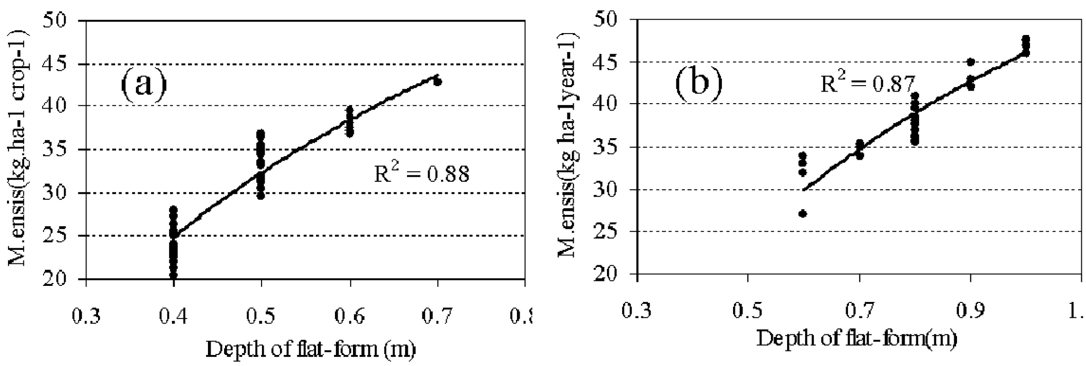

Fig. 6. Correlation between yields of *M. ensis* and depth of flat-form in My Xuyen (a) and Dong Hai (b).

This optimal model can explain 45% of the variance in *M. ensis* yields (Table 4).

Similarly, in DH, the model constructed using 6 independent variables (x_{1sm}, x_{2sm}, x_{3sm}, x_{4sm}, x_{5sm}, and x_{6sm}) explained 59% of the variance in *M. ensis* yields. The optimal model (AIC=138, R^2=0.56) was constructed using only one variable, *x1sm*, and explained 56% of the variance in *M. ensis* yields. The model is represented as follows:

$$y_{sm}=1.167+1.950\ x_{1sm} \quad (2)$$

The results of both univariate (Fig. 5) and multivariate regression analyses (Table 4) confirmed that water exchange is the principal factor that enhanced yields of *M. ensis*. In addition, these results also showed that farms with deeper flat-forms had higher yields of *M. ensis* than those with shallow flat-forms (Fig. 6). Furthermore, yields of *M. ensis* were higher in farms with deeper ditches ($p<0.01$) in both shrimp-rice paddy rotation and integrated shrimp-mangrove systems.

3.3. Variations in CL

Size density diagrams of *M. ensis* in MX are shown in Fig. 7, with CL for the early crop in January with a peak concentration of 18.0–23.0 mm. Other months, however, show broader (less concentrated) density peaks for CL. CL appeared to vary between 18.0 and 30.0 mm, and there were significant differences in CL between the different months ($p<0.01$),

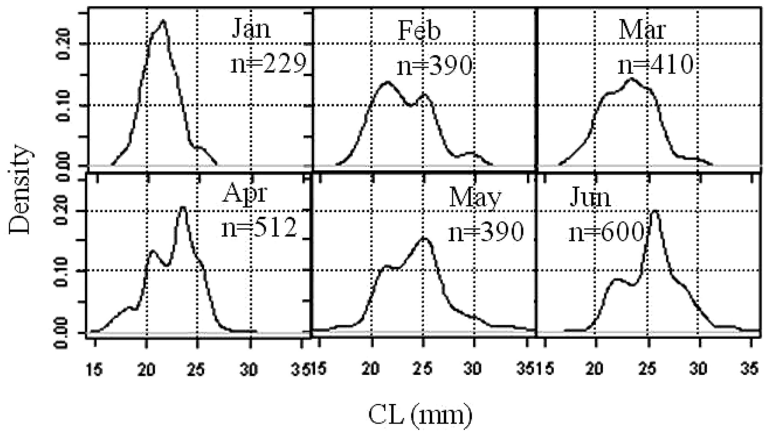

Fig. 7. Size density of carapace length (CL) for *M. ensis* in the My Xuyen District at each of the 6 sampling times; n : total number of shrimp in 4 farms per month.

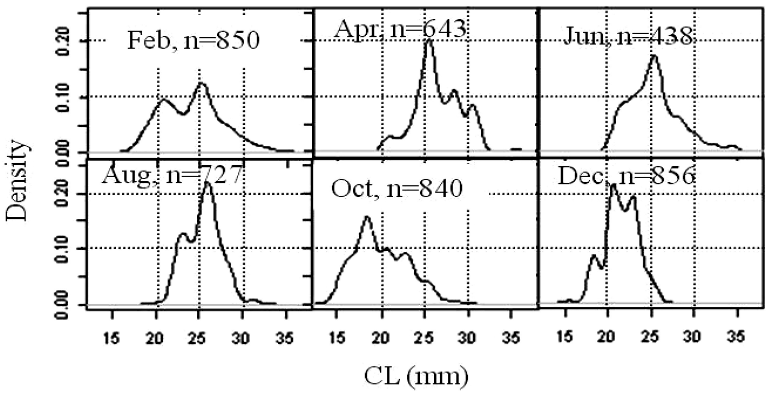

Fig. 8. Size density of carapace length (CL) for *M. ensis* in the Dong Hai District at each of the 6 sampling times; n : total number of shrimp in 4 farms.

except for February–March ($p > 0.05$). Similarly, the size density structure of CL for the 6 sampling periods in DH (Fig. 8) showed significant differences in CL between the different months ($p < 0.01$), except for June–August ($p > 0.05$).

Differences in salinity, depth of ditch, and depth of flat form for farms in MX and DH are shown in Tables 5 and 6. The flat-form depth of the farms and depth of the ditches in both MX and DH did not differ with respect to location or the months sampled. However, the salinity values were quite different between the locations. The salinity values in DH were much higher than those in MX. Furthermore, in MX, the salinities in April–June were higher than those in January–February.

4. Discussion

Coastal shrimp farming started in Vietnam in the 1970s, with development of extensive farming systems. *Metapenaeus ensis* farming has declined in recent years, possibly because of mangrove forest clearing, over-harvesting, and urbanization (Johnston *et al.*, 2000a). The natural shrimp harvest in MX was 181 kg $\cdot ha^{-1}$

Table 5. Depth of ditches (m), depth of flat-forms (m) and salinity measured during the six sampling periods in MX (mean±standard deviation).

	January (N=16)	February (N=16)	March (N=16)	April (N=16)	May (N=16)	June (N=16)
Flat-form depth (m)	0.4±0.1	0.4±0.1	0.45±0.1	0.5±0.1	0.5±0.1	0.5±0.1
Ditch depth (m)	0.8±0.2	0.7±0.2	0.8±0.2	0.8±0.2	0.9±0.1	0.8±0.2
Salinity	15.5±2.0	15.5±1.5	15±2.2	19.7±2	20.0±3	19.5±2.3

Table 6. Depth of ditches (m), depth of flat-forms (m) and salinity measured during the six sampling periods in DH (mean±standard deviation).

	February (N=16)	April (N=16)	June (N=16)	August (N=16)	October (N=16)	December (N=16)
Flat-form depth (m)	0.4±0.2	0.4±0.2	0.4±0.1	0.45±0.2	0.4±0.2	0.4±0.2
Ditch depth (m)	0.8±0.2	0.7±0.5	0.8±0.1	0.8±0.1	0.9±0.2	0.8±0.2
Salinity	25.0±2.5	30.0±2	31.0±1.2	30.0±1.2	29.0±3.1	29.0±2.2

in 1997 (Be *et al.*, 2003). Currently, the harvest is about 31.0±5.9 kg•ha^{-1}•year^{-1}. The harvest of *M. ensis* in mangrove habitats was 100−600 kg•ha^{-1} in 1993−1994 (Binh and Lin, 1995), whereas now it is about 39.2±4.7 kg•ha^{-1}•year^{-1}. Thus, the income generated by *M. ensis* harvests is declining. This species, however, is still very important to local residents because natural stocks are free. The farming of *M. ensis* has been a substantial help to poor shrimp farmers in the MD, where the GDP per capita was US$ 1,113 in 2009 (Anonymous, 2011b).

Shrimp culturing is the primary income source for residents in both MX and DH districts, with combined *M. ensis* and *P. monodon* polycultures common in all farms. However, variations in *P. monodon* yields probably reflect household investment levels. For this reason, the *P. monodon* yields were selected as one of the main components of factor 1 and could explain the variability in the *M. ensis* yields.

Multivariate analyses confirmed that *M. ensis* and *P. monodon* populations on shrimp farms are not in competition. The correlation between *M. ensis* and *P. monodon* yields in the MX and DH districts was significantly low, i.e., 0.02 and 0.11, respectively. This is because *P. monodon* was stocked at a low density in these systems, and the wild-stock density of *M. ensis* was also low.

Water exchange is the best mechanism for recruitment of post-larval *M. ensis* in farms. We found that *M. ensis* yields depend strongly on the number of water exchanges. However, the waters of the MD coastal region are highly turbid (Anonymous, 2010e). Sediment can quickly fill ditches and accumulate on flat-forms, especially if water exchanges occur multiple times in a year. Farmers must then incur the costs of annually excavating the sediment (Preston *et al.*, 2003). Yields of *M. ensis* are also dependent on factors such as wild-seed abundance, the water levels of flooded farms, farm design, and water quality (Binh *et al.*, 1997).

Our results show that recruitment of *M. ensis* is strongly dependent on the frequency and volume of water exchanges on farms. The size density structures of *M. ensis* populations varied throughout the year, with one to several peaks in the CL per month; CL varied between 18 mm and 30 mm. CL varied from month to month in both MX and DH, implying that yields of this species are sustained throughout the year.

The yield of *M. ensis* in MX was lower than that in DH because *M. ensis* in MX is affected to a greater extent by natural conditions. Shrimp culture farming operates only during the dry season (6 months) in MX. However, local residents can get other income from cultivating paddy rice in the same area. It is an effective way to use agricultural land, and it can be considered to be applicable to coastal areas. The integrated shrimp-mangrove system also has low yields. However, the average area per household is 1.7 ha. The existence of integrated shrimp-mangrove farms not only provides a livelihood for local residents but also helps to sustain mangrove forests. Both of these systems require low investments and are a consistent income source for local residents.

Although *M. ensis* yields are lower than those of *P. monodon*, the species contributes significantly to the alleviation of poverty in coastal communities (Joffre and Schmitt, 2010). *Metapenaeus ensis* not only supplements the incomes of farmers but also has positive impacts on regional biodiversity and contributes to the natural balance of ecological systems (Islam *et al.*, 2004)

5. Conclusions

Populations of *M. ensis* are combined with those of *P. monodon* in improved extensive farming systems throughout MD. *Metapenaues ensis* populations rely on the recruitment of wild seed, with multiple recruitments during the year representing the opportunity for sustained yields. *Metapenaeus ensis* cultures yield significant economic support to low-income populations, requiring only small investments to realize modest returns. The shrimp are harvested for the market; however, yields of *M. ensis* are lower than those of *P. monodon*. For this reason, farmers cannot depend on *M. ensis* alone for their livelihood.

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