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Shrimp yields and harvest characteristics of mixed shrimp–mangrove forestry farms in southern Vietnam: factors affecting production

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Abstract

Shrimp yields and harvest characteristics were monitored at mixed shrimp–mangrove forestry farms in two state forestry–fisheries enterprises, Tam Giang 3 and 184, in Ca Mau province, southern Vietnam. The aim was to identify key factors contributing to poor and declining shrimp production in the region over recent years. Shrimp yields were highly variable between farms but were generally low with mean annual yields of 286 ± 106 kg ha^{-1} yr^{-1} and income of 388 ± 146 USD ha^{-1} yr^{-1}. Secondary fisheries products, such as fish and mud crabs, increased total farm production by 24% (54 kg ha^{-1} yr^{-1}) and income by 14% (71 USD ha^{-1} yr^{-1}). Shrimp yields peaked between July–October and March–May, which is consistent with the traditional ''Mua'' and ''Tong'' harvest seasons, respectively. Yields were significantly higher at enterprise Tam Giang 3 and were generally higher at extensive farms than traditional farms. A correlation analysis of water quality and technical parameters revealed that pond depth ($r = 0.62$), maximum fluctuation in pond depth ($r = -0.55$) and ammonia concentration ($r = -0.63$) were significantly correlated with shrimp yields ($P < 0.05$). Stepwise multiple regression revealed the model: Yield = 1.73–7.8 * NH_3–N + 0.03 * Pond Depth ($r^2 = 0.63$). *Metapenaeus ensis* and *M. lysianassa* are the dominant shrimp species cultured, representing 48–50% and 31–32% of harvests, respectively. *Penaeus indicus* is the third most important species, although it represents a much smaller proportion (6.7–9.7%) of total harvest. All three species vary in abundance with season, with *M. ensis* being dominant in the wet and *M. lysianassa* dominant in the dry. The size

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of shrimp harvested is small, with a mean total length of 49.7 ± 0.18 mm and 50.6 ± 0.2 mm for *M. ensis* and *M. lysianassa*, respectively. Key factors contributing to poor and declining shrimp yields in Ca Mau province include inappropriate management techniques and pond design, poor wild seed recruitment, and reliance on small, low-value Metapenaeids as culture species. Recommendations to improve current farm production are presented.

Keywords: Shrimp; Penaeid; Yield; Harvest; Vietnam; Extensive culture; Integrated farming; Mangroves

1. Introduction

Rapid expansion of shrimp aquaculture in Vietnam over recent years has resulted in its emergence as one of the largest shrimp-producing nations in the world, currently ranking seventh in total global shrimp production (Boyd and Clay, 1998; Rosenberry, 1998). It is estimated that 590,000 ha of water surface were under aquaculture activities in 1995 and, of that area, 265,000 ha (45%) were brackishwater shrimp ponds producing 75,000 mt of shrimp (Lovatelli, 1997). The Mekong Delta is by far the most productive area for brackishwater aquaculture and freshwater fisheries in Vietnam. In 1997, shrimp farming occupied 186 700 ha, representing extensive, improved extensive, semi-intensive, shrimp–mangrove and shrimp–rice culture systems (Phuong and Hai, 1998). Total production of cultured shrimp in the Mekong Delta achieved 48,664 mt during 1997, with 21,000 mt produced from the Minh Hai province alone (now divided into Ca Mau and Bac Lieu provinces) (Phuong and Hai, 1998). There are currently 134 hatcheries in the Mekong Delta producing over 217 million postlarvae annually. Production figures vary dramatically between the various shrimp culture systems with semi-intensive farms producing between 1000 and 2000 kg ha^{-1} yr^{-1}, whereas extensive farms produce 100–400 kg ha^{-1} yr^{-1} (Binh and Lin, 1995).

Although the rising importance of shrimp aquaculture in southern Vietnam has brought considerable financial benefits to local communities, the rapid and, to a large extent, uncontrolled increase in brackishwater aquaculture has contributed to considerable loss of mangrove forests and environmental degradation in the Mekong Delta (de Graaf and Xuan, 1998; Johnston et al., 1999). Mangrove loss has been particularly severe in the former Minh Hai province where rates of forest clearance have been estimated at up to 5000 ha^{-1} yr^{-1}, with a reduction in forest area from 117–745 ha in 1983 to 51,492 ha in 1995 (Hong and San, 1993; Phuong and Hai, 1998). In addition to shrimp culture expansion, other factors contributing to deforestation in the Mekong Delta include increasing population pressure and demands for firewood and construction poles. Mangroves serve a large number of functions for human populations in tropical coastal regions, including the provision of housing materials, support of coastal fisheries, buffering against storms and trapping of sediments (Saenger et al., 1983; Macintosh, 1996). Such extensive mangrove clearance has threatened regional supplies of firewood and construction materials, and has led to declines in plankton and shrimp seed densities, saltwater intrusion and accelerated coastal erosion (Sinh, 1994; Hong, 1996; Johnston et al., 2000).

To ease the land use conflict between mangrove silviculture and shrimp aquaculture in the Mekong Delta, State Forestry–Fisheries Enterprises (SFFEs) were established where shrimp are cultured together with mangrove silviculture in integrated farming systems. Their purpose is twofold, to promote reforestation and slow the rate of mangrove destruction whilst promoting poverty alleviation among coastal communities through shrimp culture. Although the establishment of SFFEs has slowed the rate of deforestation, it is doubtful that poverty alleviation has been achieved as shrimp yields in Ca Mau province have declined in recent years to 100–600 kg ha^{-1} yr^{-1} (Binh and Lin, 1995; Binh et al., 1997). In response to these issues, a 3-year collaborative research project was undertaken to identify the factors responsible for low and declining yields at mixed shrimp–mangrove forestry farms in Ca Mau province, and to investigate methods to optimise shrimp and wood production. Data to date indicate that shrimp yields have declined due to a combination of disease outbreaks, recruitment failure, and poor farm design and management techniques (de Graaf and Xuan, 1998; Johnston et al., 1999, 2000). This paper documents shrimp yields, species composition and size of shrimp harvested at mixed shrimp-mangrove forestry farms in two SFFEs in Ca Mau province during 1996 and 1997. The relationships between shrimp yields and a range of water quality and farm/pond parameters were determined using correlation and regression analyses to identify which factors were associated with declining shrimp yields.

2. Methods

2.1. Study site and farming system

Ca Mau province is the southernmost province of the Mekong Delta, situated on the Ca Mau peninsula (Fig. 1). The study was conducted at two adjacent SFFEs in Ca Mau province: Tam Giang 3 and 184, which have 236 and 1018 farm households, respectively (Fig. 2). Mixed shrimp–mangrove forestry farms in Ca Mau province are either extensive, with both tidal recruitment of wild seed and stocking of hatchery-reared postlarvae at low densities, or traditional, which are totally dependent on tidal recruitment of wild seed. Within each farming system, there are two general farm types: mixed and separate, the former having mangroves planted on the pond levees, whereas the latter have the levees cleared of vegetation (Johnston et al., 1999). Each farm has a single pond that consists of a number of long (up to 1000 m), narrow (3–6 m wide) channels dug either through (mixed) or adjacent (separate) to the forest, and they are separated by levees.

Ponds are connected to the adjacent waterway via a single sluice gate. The gates, made of either wood or cement, are composed of a series of boards that are raised and lowered to allow water to flow into and out of the pond. Every 15 days, recruitment and harvest occur on consecutive flood and ebb tides for 4–5 days and nights of the spring tide period (Johnston et al., 1999, 2000). On the flood tide, the sluice gate is opened and postlarvae, juvenile and adult shrimp swim into the pond. On the following ebb tide, the pond is drained and shrimp and other fisheries products are harvested in a bag net positioned at the back of the sluice gate. After recruitment and harvesting, the sluice

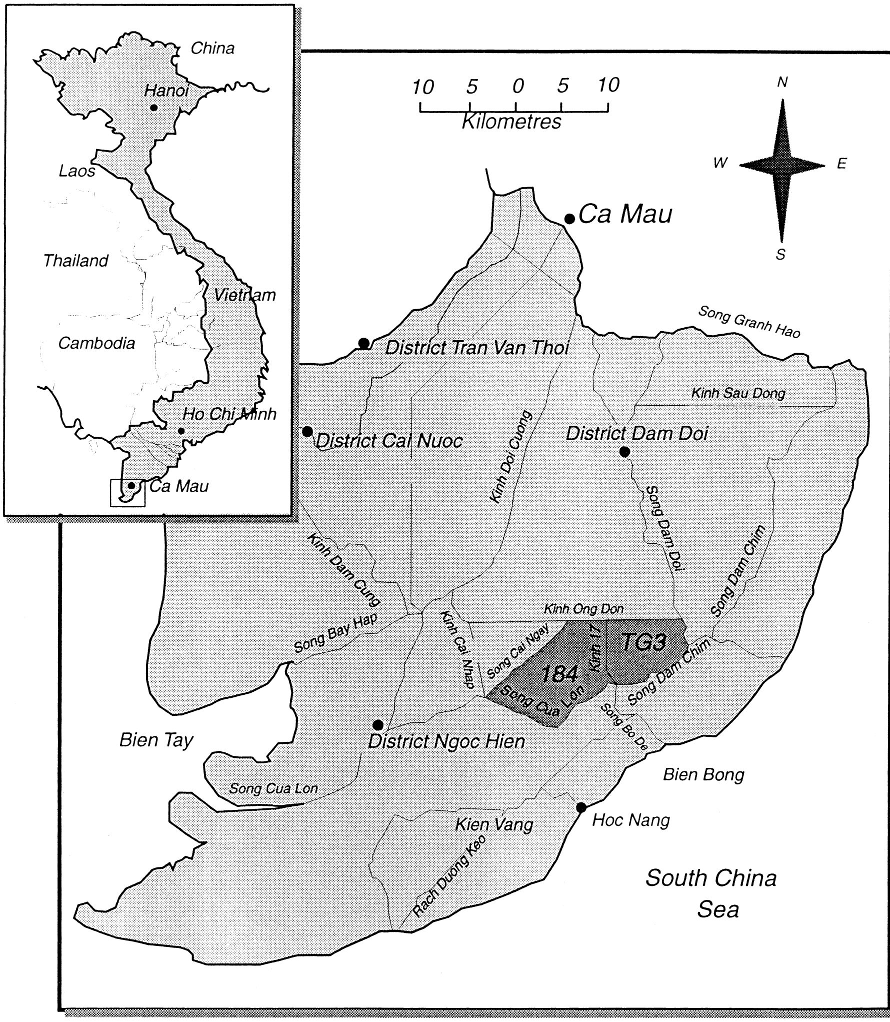

Fig. 1. Location map of enterprises Tam Giang 3 and 184 in Ca Mau province, Southern Vietnam.

gate is closed for a 10–12-day growout period. During this period, there is little or no water exchange, supplementary feeding, aeration, liming or fertiliser treatment (Johnston et al., 1999).

2.2. General survey of shrimp yields

Six farms in enterprise Tam Giang 3 (11, 12, 20, 22, 23, 39) and enterprise 184 (18, 24, 25, 27, 33, 44) were selected based on their location (river versus canal) and farm type (mixed/separate) as part of a general survey on shrimp culture in the region (Fig. 2). Characteristics of the farms are presented in Table 1. Farmers involved in the general

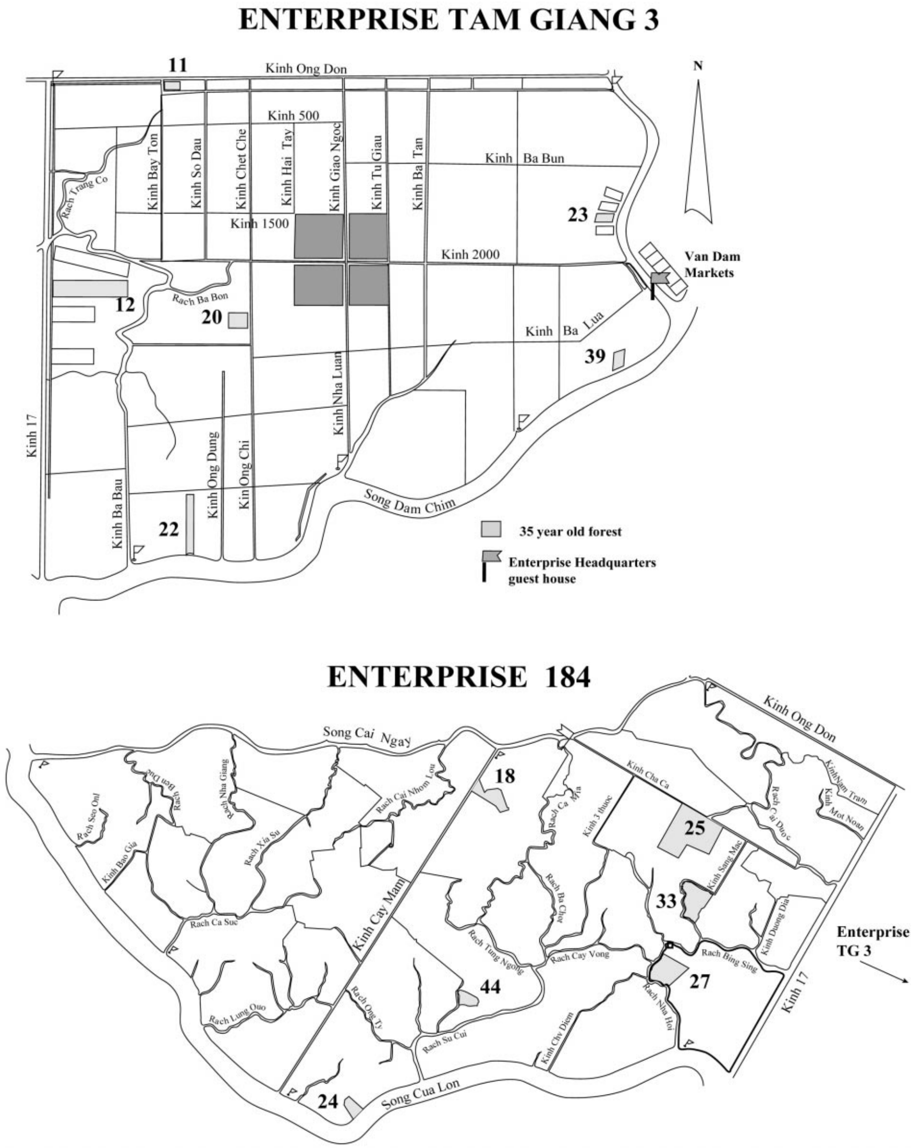

Fig. 2. Location map of farms selected for the general survey in enterprises Tam Giang 3 and 184, Ca Mau province. Farms are numbered according to enterprise policy.

survey recorded their daily yields (kg) and income (Dong) from shrimp culture per bi-monthly harvest from July 1996 to June 1997. These figures were converted to kg ha^{-1} and USD ha^{-1} (pond area) for analyses. Predicted annual shrimp yields (kg ha^{-1} yr^{-1}) and income (USD ha^{-1} yr^{-1}) for each farm were calculated using the sum of shrimp yields and income over x months and extrapolating to 12 months. Water quality

Table 1
Characteristics of farms involved in the general survey.
The farming system for all farms in the general survey was extensive. TG denotes Tam Giang. Farm and pond area were not recorded for farm 39.

Enterprise	Farm ID	Farm location	Farm type	Farm area (ha)	Pond area (ha)	Sluice gate width (m)	Sluice gate type
TG3	11	Canal	Separate	11.6	1.7	1	Cement
TG3	12	River	Mixed	13	2.6	1	Cement
TG3	20	Canal	Mixed	3.8	0.5	0.8	Wood
TG3	22	River	Separate	10	1.1	0.8	Wood
TG3	23	River	Separate	1.8	0.68	1	Cement
TG3	39	River	Separate			0.8	Wood
184	18	River	Mixed	10.1	3.6	1	Cement
184	24	River	Mixed	6.3	2.1	1	Cement
184	25	Canal	Mixed	7.4	4.4	1	Cement
184	27	Canal	Mixed	17	5.9	0.8	Wood
184	33	Canal	Mixed	7.1	2.7	1	Cement
184	44	Canal	Mixed	4.2	2.4	0.8	Wood

(refer to parameters outlined in Section 2.4) was recorded at 2-month intervals during 1996 at two positions in ponds: near the sluice gate (Pond A) and at the back of the pond (Pond B). Measurements were taken at 20 cm water depth and between 7:30 am and 10:00 am.

2.3. Socio-economic survey

Annual yield (kg ha^{-1} yr^{-1}) and annual income data (USD ha^{-1} yr^{-1}) from shrimp culture and secondary products (fish and mud crab) were collected from 211 farms in both enterprises during an extensive socio-economic survey conducted by Can Tho University during 1996 under the supervision of the Network for Aquaculture Centres in Asia-Pacific (NACA). Farms were classified according to enterprise (Tam Giang 3, 184), farm system (extensive/traditional) and farm type (mixed/separate).

2.4. Management technique experiment

Water quality and shrimp yields were monitored concurrently at four adjacent mixed farms and four adjacent separate farms to determine whether pond water quality significantly affected shrimp yields. Farms are indicated on Fig. 2 with those next to and including farm 12 being mixed and those next to and including farm 23 being separate. Within each farm group, two farms continued their typical 15-day growout cycle and two had extended growout periods of 60 days (as part of a broader study to determine whether a longer growout period increased yields). Total shrimp yields (kg ha^{-1}) after each growout period were recorded by addition of bag net harvests over successive days and nights of the corresponding spring tide period. The following water quality parameters were monitored between 7:00 am and 9:00 am every second day: pH, salinity, temperature (°C), dissolved oxygen (DO) (mg l^{-1}), turbidity (secchi disc depth cm), water depth (cm), redox potential (Eh) of the pond bottom (mV) and chlorophyll *a* (μg l^{-1}). Parameters were measured at two positions: Pond A, near the sluice gate and Pond B at the back of the pond and at two pond depths: 10 cm from the surface and 10 cm from the bottom. Ammonia nitrogen-un-ionized (NH_3–N) (mg l^{-1}), nitrite (NO_2–N) (mg l^{-1}), phosphate (PO_4–P) (mg l^{-1}) and dry soil pH were measured in each pond at recruitment and 15-day intervals thereafter. Duplicate 500 and 250 ml water samples were taken for nutrient and chlorophyll *a* analyses, respectively. Pharmacia Biochrom Palintest water test kits were used for nutrient determination and a modified method from Parsons et al., (1985) and Stirling (1985) was used for chlorophyll *a* determination.

2.5. Analyses of yield data

Significant differences in daily yields (kg ha^{-1}) among enterprise, farm type, farm location and season (wet versus dry) for farms involved in the general survey were determined by one-way ANOVA ($n = 410$). Significant differences in annual shrimp yields (kg ha^{-1} yr^{-1}) among enterprise, farm type and farm system for the 211 farms involved in the socio-economic survey were determined by a three-way fixed-factor ANOVA ($n = 211$) (Sokal and Rohlf, 1995).

Multiple regression analyses (Sokal and Rohlf, 1995) were performed to determine which factors significantly affected shrimp yields. The factors analysed were divided into water quality parameters and technical parameters and were performed on three data sets as detailed below. The water quality parameters analysed were: pH, salinity, temperature, dissolved oxygen, turbidity, water depth, pond bottom Eh, chlorophyll *a*, NO_2–N, NH_3–N, PO_4–P. The technical parameters analysed were pond age (yr), pond area (ha), farm area (ha), mangrove age (yr), mangrove density (trees ha^{-1}), sluice gate width ratio (m ha^{-1}), the ratio of gate width to pond area, and dry soil pH. These technical parameters were selected based on their potential impact on harvests.

(1) Socio-economic data: technical parameters versus annual shrimp yield per farm (kg ha^{-1} yr^{-1}), $n = 211$.

(2) General survey data: technical parameters versus mean yields per farm (kg ha^{-1}) between July 1996 and April 1997, $n = 10$. Water quality data were not collected concurrently with yield data and were subsequently not analysed.

(3) Management technique experiment: mean water quality parameters over 15- and 60-day growout periods versus the respective yield (kg ha^{-1}) for that period, $n = 18$. The maximum fluctuation in water quality parameters over each time period was also correlated against yield for that period. Technical parameters were analysed against mean yield per farm (kg ha^{-1}); $n = 8$.

2.6. Harvest species composition and size

A sub-sample of harvests from farms 12 and 23 in Tam Giang 3 was taken on each consecutive night of the spring tide between July 1996 and June 1997. Each harvest

Table 2
Mean annual shrimp yields and income generated from shrimp for farms at SFFE Tam Giang 3 and 184 from data collected during the general survey and socio-economic survey
All values are per pond area (ha). Annual shrimp yields and income from the general survey are predicted based on the sum of daily yields and income over x months and extrapolated to 12 months. Total yields and total income include secondary fisheries products such as mud crabs/fish.

Parameter	General survey		Socio-economic survey	
	Mean ± 1 SE	Range	Mean ± 1 SE	Range
Shrimp yields (kg ha^{-1} yr^{-1})	286 ± 106	12–1166	224 ± 32	0–2985
Income earned (USD ha^{-1} yr^{-1})	388 ± 146	54–1626	508 ± 78	0–10606
Total yields (kg ha^{-1} yr^{-1})			278 ± 40	0–2985
Total income (USD ha^{-1} yr^{-1})			579 ± 82	0–10606

sample was fixed in 8% seawater formalin, identified to species and the total length (tip of rostrum to tip of telson) of each shrimp recorded.

3. Results

3.1. Yields

Predicted annual shrimp yields were highly variable between mixed shrimp–mangrove forestry farms in enterprises Tam Giang 3 and 184, ranging from 12 to 1166 kg ha^{-1}

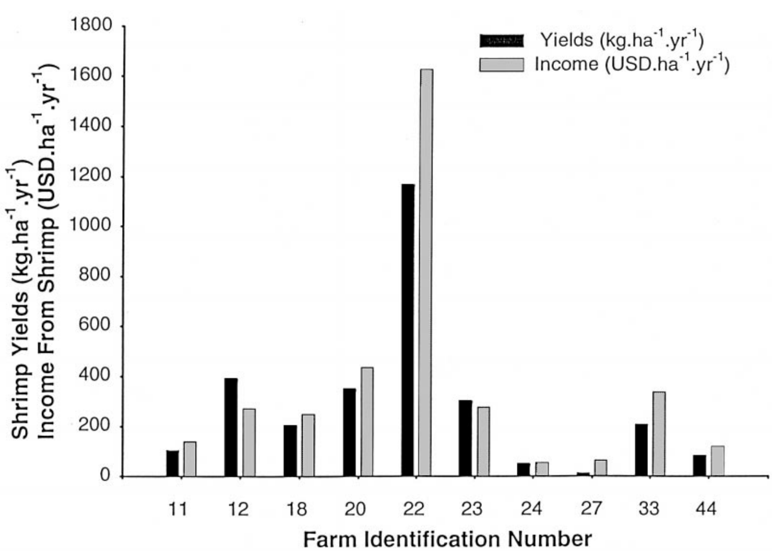

Fig. 3. Predicted annual shrimp yields and income earned from shrimp at each of the general survey farms in 1996 and 1997 based on the sum of yields and income over x months and extrapolating to 12 months. All values are per pond area (ha) and do not include secondary products. Farms 12 and 23 include yield and income data in April–June 1997.

yr^{-1} with a mean of 286 ± 106 kg ha^{-1} yr^{-1} (Table 2; Fig. 3). Income earned from shrimp was also highly variable, ranging from 54 to 1626 USD ha^{-1} yr^{-1} with a mean of 388 ± 146 USD ha^{-1} yr^{-1}. Farm 22 was particularly successful with yields (1166 kg ha^{-1} yr^{-1}) and income (1626 USD ha^{-1} yr^{-1}), greater than four times than the average (Fig. 3). Mean yields and income from farms involved in the general survey are

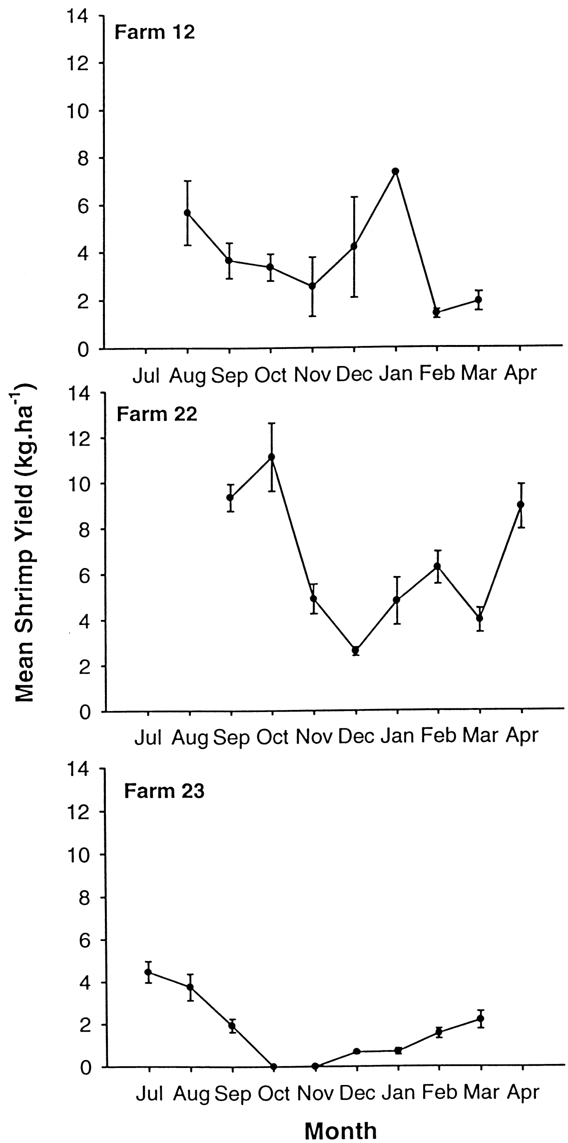

Fig. 4. Mean daily shrimp yields per month at farm 12, 22 and 23 between July 1996 and April 1997. 1 SE are indicated. Daily shrimp yields were recorded from individual day and night harvests during bi-monthly spring tide periods. Note the considerably higher yields at farm 22.

Table 3
Mean daily shrimp yields (general survey data) and annual shrimp yields (socio-economic survey data) with respect to farm parameters
All values are per pond area (ha). Corresponding ANOVA data are indicated in text.

Farm parameter		Mean daily shrimp yields (kg ha^{-1}) $\pm$ 1 SE	Mean annual shrimp yields (kg ha^{-1} yr^{-1}) $\pm$ 1 SE
Enterprise	184	4.6 ± 0.2	246 ± 39
	Tam Giang 3	1.3 ± 0.1	204 ± 54
Farm location	River	3.9 ± 0.2	
	Canal	2.5 ± 0.3	
Farm system	Extensive		216 ± 40
	Traditional		251 ± 58
Farm type	Mixed	2.2 ± 0.2	233 ± 52
	Separate	4.9 ± 0.3	218 ± 29
Season	Wet	2.9 ± 0.3	
	Dry	1.85 ± 0.2	

consistent with data recorded during the socio-economic survey where mean shrimp yields and income were 224 ± 32 kg ha^{-1} yr^{-1} and 508 ± 146 USD ha^{-1} yr^{-1}, respectively (Table 2). Secondary fisheries products such as mud crabs and fish increased mean production from ponds by 24% (54 kg ha^{-1} yr^{-1}) and income by 14% (71 USD ha^{-1} yr^{-1}) (Table 2).

Shrimp yields recorded from July 1996 to April 1997 at farms 12, 22 and 23 peaked in July–October and March–April (Fig. 4). Farm 23 reported no yields in October–November 1996 due to difficulties with water quality and an outbreak of White Spot at that time.

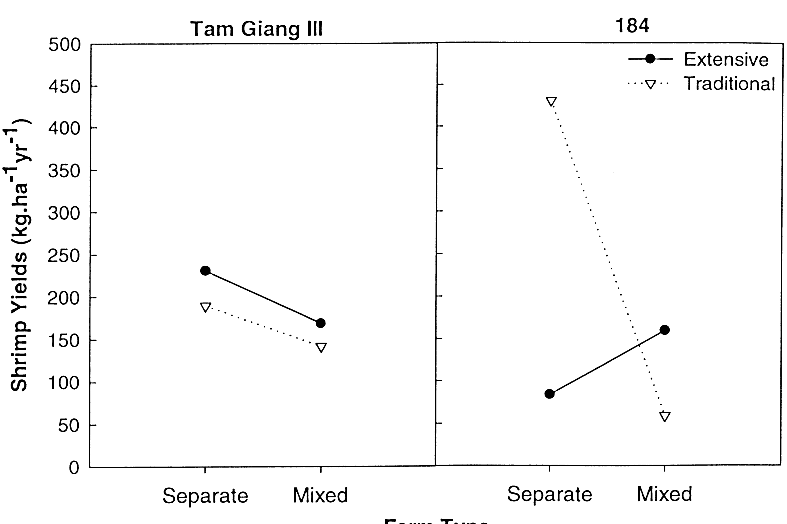

Fig. 5. Three-way interaction between enterprise, farm type and farm system on annual shrimp yields collected from 211 farms during the socio-economic survey. $n = 211$; $P < 0.05$.

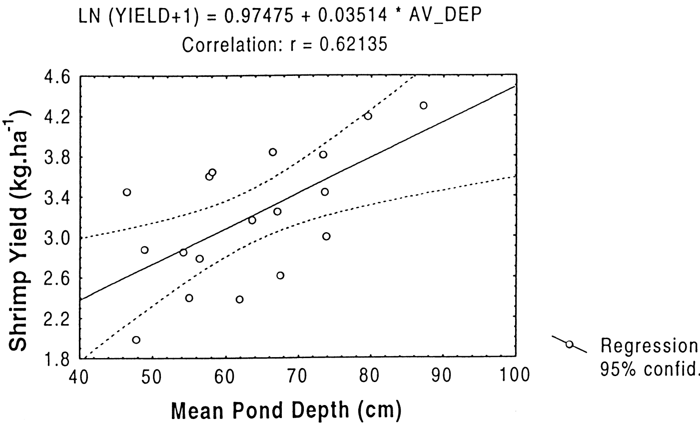

Fig. 6. Correlation between mean shrimp pond depth and shrimp yields (management technique experiment) during 1996–1997, Ca Mau province, southern Vietnam. Shrimp yield data were transformed using $\ln(n+1)$ for normality.

Daily shrimp yields recorded during the general survey were significantly higher at separate farms than mixed farms ($F_{(1,402)} = 73.1$; $P = 0.00$), with farms on rivers more successful than farms on canals ($F_{(1,402)} = 8.6$; $P = 0.004$) (Table 3). However, after removing the particularly successful farm 22 from the analysis (separate farm located on the river), there were no significant differences in yields between farm type and farm location. There were significantly higher yields at enterprise Tam Giang 3 than 184 ($F_{(1,287)} = 44.9$; $P = 0.00$) and significantly higher yields during the wet season than the dry season ($F_{(1,287)} = 15.1$; $P = 0.0001$) (Table 3).

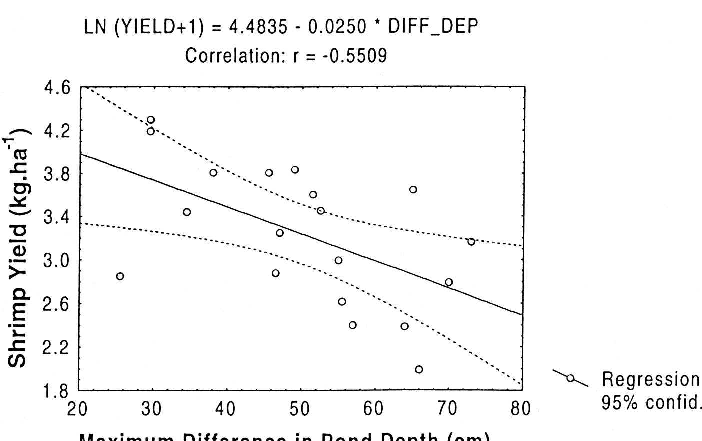

Fig. 7. Correlation between maximum difference in pond depth and shrimp yields (management technique experiment) during 1996–1997, Ca Mau province, southern Vietnam. Shrimp yield data were transformed using $\ln(n+1)$ for normality.

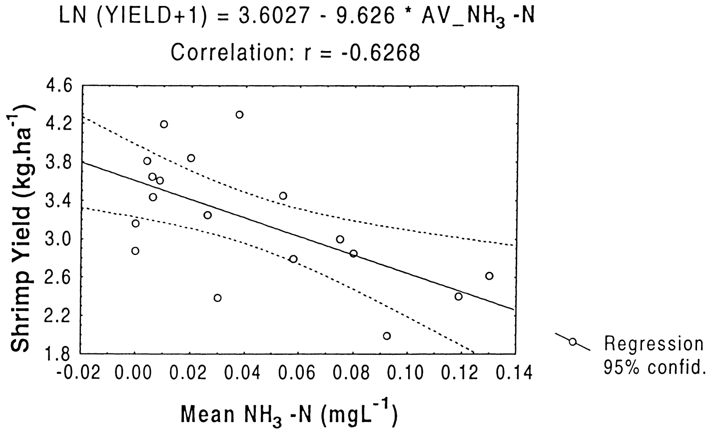

Fig. 8. Correlation between mean ammonia concentration and shrimp yields (management technique experiment) during 1996–1997, Ca Mau province, southern Vietnam. Shrimp yield data were transformed using $\ln(n+1)$ for normality.

Analysis of shrimp yields at farms from the socio-economic survey revealed there was a significant three way interaction effect of enterprise * farm system * farm type ($F_{(1,194)} = 5.99$; $P = 0.015$). Mean annual shrimp yields for each farm parameter are presented in Table 3 and the three-way interaction presented in Fig. 5. At enterprise Tam Giang 3, extensive farms had higher yields than traditional farms and separate farms had higher yields than mixed farms. At enterprise 184, however, separate farms had considerably higher yields than mixed ones for traditional farms, whereas mixed farms had higher yields than separate ones for extensive farms.

Correlation and stepwise multiple regression analyses of shrimp yields versus water quality parameters for the management technique experiment revealed that, of the water quality parameters, only pond depth ($r = 0.62$), maximum fluctuation in pond depth ($r = -0.55$) and ammonia concentration ($r = -0.63$) were significantly correlated with shrimp yields ($P < 0.05$). The deeper the ponds, the higher the yields and the greater the fluctuation in pond depth the lower the yields (Figs. 6 and 7). As would be expected, the higher the concentration of ammonia, the lower the yields (Fig. 8). Stepwise multiple

Table 4
Regression summary for shrimp yield (dependent variable) versus water quality parameters (independent variables) for the management technique experiment
Yield data were transformed by $\ln(n+1)$. Correlation analyses on the data are summarised in Figs. 6–8. $n = 18$, $r = 0.79$, $r^2 = 0.63$, $F_{(2,15)} = 12.84$; $p < 0.00056$.

Independent variable	Beta	*B* coefficient	SE of *B*	*t*-value	*P*-level
Constant		1.73	0.62	2.8	0.013
Mean NH_3–N	−0.51	−7.82	2.48	−3.16	0.006
Mean pond depth	0.50	0.02	0.01	3.12	0.007

regression of mean water quality parameters versus shrimp yield (kg ha^{-1}) (transformed $\ln(n+1)$) revealed the model:

$$\text{Yield} = 1.73 - 7.8^{*}\,NH_3\text{–N} + 0.03^{*}\,\text{Pond Depth}$$

An r^2 of 0.63 indicates that 63% of the variation in shrimp yields can be explained by the significant variables in the model (Table 4). Both ammonia and pond depth had slopes significantly different from zero ($P < 0.01$). The similar magnitude of the beta coefficients for ammonia and pond depth indicate they have equal relative contribution in the prediction of shrimp yield. A plot of residuals against the dependent variable (yield) revealed a symmetrical scatter about the x-axis indicating this model is appropriate. Likewise, the plot of predicted versus observed shrimp yields generated from the model was accurate. There were no significant correlations between technical parameters and shrimp yields (kg ha^{-1} yr^{-1}).

3.2. Harvest characteristics

Metapenaeus ensis and *M. lysianassa* were the dominant species harvested from culture ponds, representing 48–50% and 31–32% of harvests, respectively (Fig. 9). *Penaeus indicus* was the third most important species, although it represents a much smaller proportion at 9.7% and 6.7% for farms 12 and 23, respectively. A range of other species including *M. spinulatus*, *Macrobrachium equidens* and *P. styliferus* together represented less than 10% of the total harvest. Abundance of *M. ensis* and *M. lysianassa* varied considerably throughout the year and was reflected in their proportion of total harvest (Fig. 10). From September to January, *M. ensis* was the dominant species, whereas from April to August, *M. lysianassa* was dominant. Due to the late wet

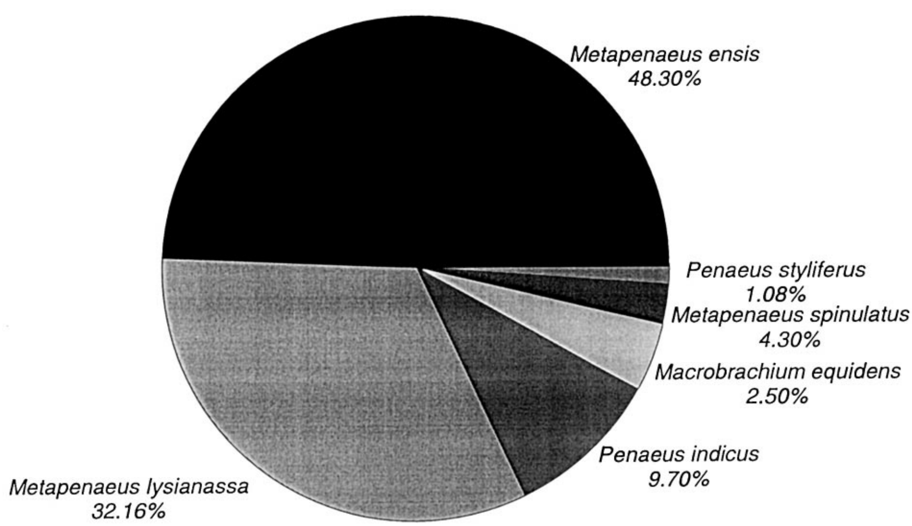

Fig. 9. Proportion of shrimp species harvested at Farm 12 between July 1996 and February 1997. Species representing less than 1% of total harvest are not included.

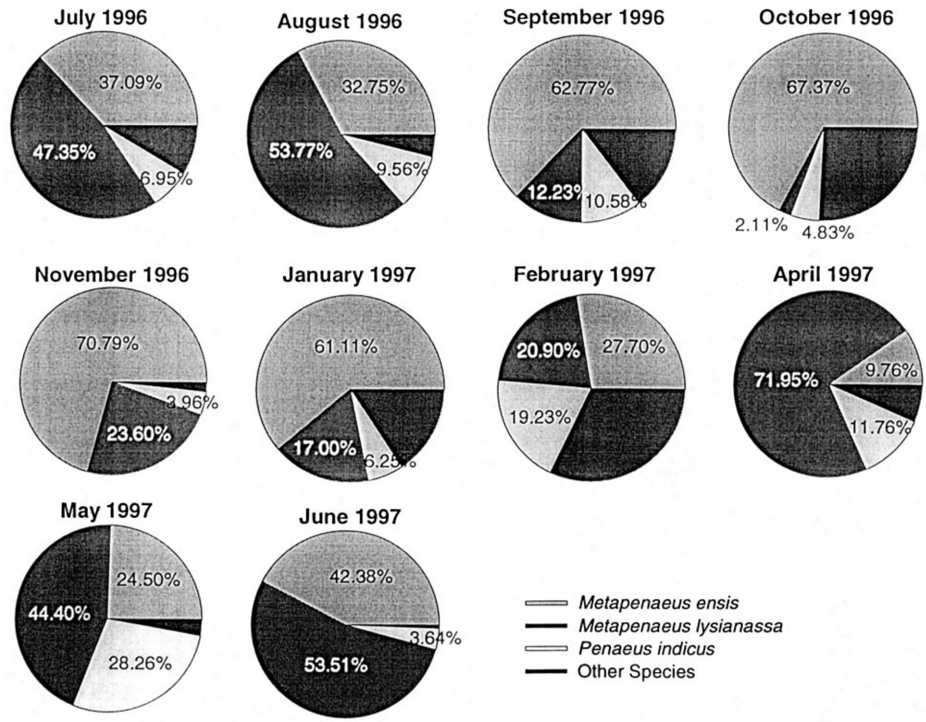

Fig. 10. Annual variation in the proportions of shrimp species harvested at Farm 12 from July 1996 to June 1997. Only the three dominant species *M. ensis*, *M. lysianassa* and *P. indicus* are indicated.

season in 1996, where the highest rainfall was recorded in October, this corresponds with *M. ensis* being dominant in the wet season and *M. lysianassa* in the dry season. February was the only month where relative abundances of all shrimp species were similar. The abundance of *P. indicus* was greatest from February to May where it represented between 9.8% and 28.3% of total shrimp harvested.

The size of harvested shrimp is generally small, with a mean total length for *M. ensis* and *M. lysianassa* of 49.7 ± 0.18 and 50.6 ± 0.20 mm, respectively (Table 5). The

Table 5
Mean total length of shrimp species harvested from farms 12 and 23 between July 1996 and June 1997
1 SE is indicated.

Species harvested	Mean total length at harvest (mm)
M. ensis	49.7 ± 0.18
M. lysianassa	50.58 ± 0.21
P. indicus	64.92 ± 1.0
M. spinulatus	57.32 ± 0.3
M. brevicornis	55.16 ± 0.57
Mac. equidens	44.89 ± 0.66
P. styliferus	44.57 ± 0.92

largest species cultured is *P. indicus*, which is harvested at 65 ± 1.0 mm. The size of harvested *M. ensis*, *M. lysianassa* and *P. indicus* varied little between July 1996 and June 1997.

4. Discussion

4.1. Yields

Mixed shrimp-mangrove forestry farms in Ca Mau province are characterised by low and highly variable shrimp yields. Mean annual shrimp yields during 1996 and 1997 (286 ± 106 kg ha^{-1} yr^{-1}; 224 ± 32 kg ha^{-1} yr^{-1}) are comparable with those of earlier surveys taken in the region (265.3 kg ha^{-1} yr^{-1}, Binh et al.,1997). They are typical of traditional extensive systems (100–400 kg ha^{-1} yr^{-1}) and shrimp–mangrove systems (100–600 kg ha^{-1} yr^{-1}) in Vietnam (Binh and Lin, 1995). Compared with other extensive farming systems in SE Asia, pond production at mixed shrimp–mangrove forestry farms in Ca Mau province is relatively low. Countries such as the Philippines produce 100–500 kg ha^{-1} yr^{-1} from traditional farms and 600–1300 kg ha^{-1} yr^{-1} from extensive farms (Primavera, 1991, 1998a). However, it must be noted that most of the extensive farms in SE Asia provide some kind of supplementary feeding (trash fish) and fertiliser that makes comparison with mixed shrimp–mangrove forestry farms difficult. The marked variation in shrimp production between farms reflects inexperience in culture techniques, poor pond design, fluctuating water quality and unreliable wild seed recruitment (Johnston et al., 1999, 2000). Consequently, farmers have been forced to rely on a low input–low output production system to minimise risks associated with shrimp farming in the region.

Although pond production is generally low, some farmers in the region are highly successful. For example, farm 22 had an annual production of 1166 kg ha^{-1} yr^{-1}, which was three times higher than the next most successful farm surveyed and four times higher than the average annual yield. Examination of differences between farm 22 and other general survey farms revealed that better management techniques were primarily responsible for the considerably higher yields. In particular, farm 22 did not suffer from pond water leakage problems, which plague the majority of local farmers, so ponds were consistently deep (generally greater than 80 cm versus a mean pond depth of 50.5 cm) with a stable water level (Johnston et al., 1999, unpublished data). The importance of this is verified by the significant positive and negative correlation between pond depth and maximum fluctuation in pond depth, respectively, with shrimp yields (Figs. 6 and 7). In addition, farm 22 was meticulous in recruitment, harvesting and pond excavation techniques, all of which contribute to higher yields. Although pond water quality is similar between farms, farm 22 had higher chlorophyll *a* concentrations, dissolved oxygen and pond bottom Eh, with minimal diurnal fluctuations in all water quality parameters (Table 6). These improved water quality parameters are primarily associated with the consistently deep ponds at this farm, and are particularly important for shrimp health and survival as demonstrated by the higher shrimp yields.

In addition to better management practices, total farm production can be improved by culturing secondary fisheries products such as fish and mud crabs, which increased mean

Table 6
Differences in mean water quality conditions between farm 22 and the 11 farms involved in the general survey Marked differences are indicated in bold. 1 SE is indicated in brackets. Position Pond A: front of pond, near the sluice gate; Pond B: back of pond. SS refers to total suspended solids.

Position	Farm	pH	Temp (°C)	DO_2 mg l^{-1}	Salinity (‰)	Turbidity (cm)	Eh
Pond A	22	7.41 (0.03)	27.06 (0.5)	3.62 (0.5)	20.8 (3.4)	31.4 (7.9)	−107 (76)
	others	7.31 (0.05)	27.93 (0.03)	3.82 (0.2)	22.05 (1.2)	32.07 (1.8)	33 (29)
Pond B	22	7.24 (0.03)	27.6 (1.4)	**4.43 (0.3)**	20.67 (5.7)	28.33 (4.4)	**5.0 (82)**
	others	7.26 (0.05)	28.38 (0.3)	**3.62 (0.3)**	22.37 (1.0)	27.38 (1.96)	**−32 (22)**

Position	Farm	NO_2–N (mg l^{-1})	NH_3–N (mg l^{-1})	PO_4–P (mg l^{-1})	Fe (mg l^{-1})	Chl *a* (μg l^{-1})	SS (g l^{-1})
Pond A	22	0.04 (0.04)	0.15 (0.06)	0.32 (0.16)	0.03 (0.01)	**0.21 (0.009)**	4.4 (0.7)
	others	0.01 (0.002)	0.12 (0.02)	0.34 (0.04)	0.04 (0.005)	**0.05 (0.07)**	4.97 (0.3)
Pond B	22	0.01 (0.004)	0.17 (0.18)	0.51 (0.07)	0.04 (0.02)	**0.18 (0.01)**	5.59 (0.40
	others	0.01 (0.002)	0.13 (0.03)	0.33 (0.03)	0.07 (0.01)	**0.01 (0.11)**	4.81 (0.38)

annual yields by 24% and mean annual income by 14%. Fish such as sea bass, gobies and mullet are often harvested with shrimp in bag nets, with sea bass earning between 1.50 and 2 USD kg^{-1} and mullet between 0.7 and 1 USD kg^{-1} (Johnston et al., 1999). Mud crabs have several benefits over shrimp including higher survival, higher profits, and faster growth rates. This is achieved with little or no capital or feed input, with crabs either cultured in ponds or mangrove forests (Dat, 1999; Genodepa, 1999; Johnston and Keenan, 1999). Cash crops such as bananas, Indian taro, pineapples and cherry trees planted on pond levee banks, particularly during the wet season when freshwater is plentiful, also increase total farm production. For example, up to 4 USD per month can be earned from vegetables, and a single cherry tree can provide 1 USD of cherries per month and depending on how many are planted, can be worth up to 30 USD per month (Johnston et al., 1999). The many benefits of integrated farming and polyculture have been well documented for extensive farming systems in SE Asia (Sanh et al., 1993; Newkirk, 1996). As shrimp yields are highly variable in Ca Mau province, diversification into other fisheries products and cash crops reduces the risk to farmers by broadening their income base. It is recommended that diversification be adopted for the long-term viability of mixed shrimp-mangrove forestry farms in Ca Mau province.

In the Mekong Delta, shrimp spawn year round with two peaks in February–March and July–August (Binh and Lin 1995). These seasonal spawning peaks are consistent with postlarval migration patterns into Song Bo De estuary and recruitment into ponds (Johnston et al., 2000). Peaks in shrimp yields at farms in enterprise Tam Giang 3 and 184 are consistent with the two major harvesting periods in Ca Mau province: ‘‘Tong’’ season from March–July with major harvests in June–July and ‘‘Mua’’ season from September–February with major harvests in October–December (Binh and Lin, 1995). Absence of yields during October–November 1996 at farm 23 corresponded with a localised White Spot disease outbreak and a deterioration in water quality. Shrimp disease (White Spot) was a major factor responsible for the marked decline in pond yields between 1993 and 1994 (de Graaf and Xuan, 1998). It remains a serious problem for farmers in Ca Mau province due to fluctuating water quality conditions and poor quality post larvae.

4.2. Variation in yields among enterprise, farm type, farm system, farm location, season

Higher shrimp yields at enterprise Tam Giang 3 than 184 are most likely attributable to differing shrimp seed recruitment based on variation in hydrodynamics of the water ways, as well as differing pond management practices between the two enterprises. Lower yields at farms on inner canals are consistent with reduced postlarval migration up long narrow mangrove creeks compared with rivers due to their smaller tidal amplitudes (Wolanski, 1992; Wolanski et al., 1980). Hydrodynamic studies of mangrove creeks indicate that water may be trapped for extended periods in long creeks, reducing recruitment potential; whereas farms on rivers have greater access to postlarvae based on superior tidal flushing. However, lack of a significant trend when farm 22 was deleted from the analysis suggests that a greater number of farm replicates is needed to clarify the effect of farm location on yield. The significantly higher yields in the wet season are most likely due to the greater abundance of larger and higher value *P. indicus* in waterways at this time and are consistent with higher yields reported during the ''Mua'' harvest season (Binh and Lin, 1997). Nevertheless, reduced abundance of these species over the past few years due to overfishing, combined with poorer water quality and associated disease outbreaks during the wet season makes shrimp culture a high risk option at this time (Alongi et al., 1999; Johnston et al., submitted for publication).

At enterprise Tam Giang 3, extensive farms had higher yields than traditional farms (by approximately 50 kg ha^{-1} yr^{-1}) and separate farms were more successful than mixed farms irrespective of farm system (by approximately 60 kg ha^{-1} yr^{-1}) (Fig. 5). Separate farms also had considerably higher yields than mixed (by approximately 400 kg ha^{-1} yr^{-1}) for traditional farms at enterprise 184, whereas mixed farms were more successful than separate for extensive farms (Fig. 5). Higher yields at extensive farms are consistent with potentially higher stocking densities due to stocking with hatchery-reared postlarvae. There are a number of reasons why separate farms generally have higher yields than mixed farms. Firstly, greater leaf-litter fall and rotting organic matter on the pond bottom at mixed farms, from overhanging mangroves, was observed to quickly foul the pond water and create an anoxic environment for the shrimp. Heavy rainfall during the wet season also washes a considerable amount of organic material into the ponds from the forest floor as well as increasing the levels of mangrove tannins in the ponds through leaching. Secondly, shading effects of the mangrove (particularly with older forests) increase heterogeneity in water quality conditions in the pond. These observations are consistent with the significant negative correlation between shrimp yields and mangrove density reported by Binh et al. (1997) who associated increased litter fall and shading with higher mangrove densities. Lastly, farmers have struggled to effectively manage both shrimp ponds and mangrove silviculture side by side in mixed systems. It has been acknowledged by Binh and Lin (1995) that mixed farms require more skills in pond design and management of both shrimp and mangroves. In contrast, separate farms allow farmers to concentrate on optimising appropriate management strategies for both shrimp culture and silviculture and allow greater control over culture practices.

The current separate farming system in Ca Mau province is consistent with the silvofisheries model Type II outlined by Fitzgerald (1997), where mangroves are separate from shrimp ponds but with a mangrove to water ratio of 60–80% mangrove and 20–40% ponds. Fitzgerald (1997) maintains that in addition to greater manageability of the pond and culture practices, higher potential production and lower construction costs, separate-model farms avoid potential toxic levels of tannins and allow for greater natural species diversity and flushing of mangrove vegetation with little disruption to natural drainage. However, it is important to control possible encroachment of ponds on the mangrove area that has been a problem of shrimp–mangrove integrated farming in Ca Mau province as well as other areas of Vietnam (Binh and Lin, 1995).

Despite data supporting the adoption of a separate farming model, an economic analysis by Binh et al., (1997) revealed that mixed farms with mangroves in 31–50% of pond area had the highest net profit and return to annual investment, whereas economic returns were lowest from ponds in which all mangroves were cleared. Gross returns were highest from separate farms (0% mangroves in ponds), which is consistent with this study, but the input costs were higher than mixed farms, thus reducing net profit. A detailed economic analysis of the inputs and outputs of mixed and separate farms is needed before conclusions on optimal land use options in Ca Mau province can be made.

4.3. Factors affecting yields

Although farms in Ca Mau province potentially suffer from acid sulphate soils (Johnston et al., submitted for publication), dry soil pH and pond pH were not significantly correlated with shrimp yields. Nevertheless, the negative effects of acid sulphate soils and pond acidity on shrimp yields are well known. Boyd (1990) and Binh et al. (1997) found dry soil pH was significantly correlated with yields from farms on the east and west coast of Ca Mau province. Unionized ammonia (NH_3–N) concentrations above 0.1 mg l^{-1} are lethal to shrimp, contributing to mortality through reduced growth and increased susceptibility to disease (Primavera, 1998a). Ammonia concentrations in ponds from enterprise Tam Giang 3 and 184 were significantly correlated with shrimp yields ($r = -0.63$). Although pond water ammonia concentrations were not lethal, declining yields with increasing ammonia concentrations is indicative of the adverse effects of ammonia on shrimp health for farms in Ca Mau province.

Ponds in enterprise Tam Giang 3 and 184 are shallow (mean depth of 50.5cm) and water depth is highly variable. This is attributable to a range of factors including insufficient depth during initial pond construction, high sedimentation rates within the Mekong River Estuary and considerable water leakage through the sluice gate and pond walls (Johnston et al., 1999). Consequently, both pond depth ($r = 0.62$) and the maximum fluctuation in pond depth ($r = -0.55$) were significantly correlated with shrimp yields, whereby farms with deep ponds and stable water levels had high yields. Water depth fluctuations up to 73 cm over a 15-day period have led to severe water quality fluctuations (Table 7). Farmers need to regularly excavate accumulated sediment

Table 7
Maximum fluctuation in pond water quality parameters over 15 and 60 days
Data were collected every second day from eight farms involved in the management technique experiment between April and June 1997.

Water depth (cm)	pH	Temperature (°C)	Salinity (‰)	DO_2 (mg l^{-1})	Turbidity (cm)	Eh	Chl a (μg l^{-1})
73	2.28	5.5	12.5	5.0	53	354	0.8

and address pond leakage problems to both increase pond depth and stabilise water level fluctuations in order to improve yields through minimising water quality-related stress on shrimp.

The finding of no significant correlation between shrimp yields and technical parameters such as pond age, mangrove density and mangrove age verifies that other factors such as water quality fluctuations, shrimp seed supply and management techniques are of much greater importance to shrimp production in Ca Mau province. Nevertheless, the analyses were based on relatively small data sets and a more extensive study using large numbers of farms is needed to verify results. Furthermore, caution is needed in the interpretation of the correlation and regression analyses based on the relative lack of control over pond stocking densities at mixed shrimp–mangrove forest farms and the resultant tenuous relationship between yields and water quality and technical parameters. Binh et al. (1997) conducted intensive sampling of farms on the east and west coasts of the Ca Mau Peninsula and found that yields were correlated with several physical (technical) parameters. On the East Coast (which is relevant to this study), shrimp yields were significantly correlated with mangrove density but not mangrove age nor area. Declines in shrimp yield with mangrove density were explained by the reduction in light penetration and increase in decayed leaf litter. Sluice gate width to pond area ratio was positively correlated with yields as a wider gate helps to flush out decayed leaves, improving water quality, and results in more shrimp seed entering the pond. Although this is likely, anecdotal evidence from farmers suggests that the time at which larvae are recruited through the sluice gate is critical for their survival in the pond and may be of great importance to overall production. Hence, although technical parameters influence yields, pond management is probably more critical to shrimp survival and overall pond production for mixed shrimp mangrove forestry farms.

4.4. Harvest characteristics

M. ensis and *M. lysianassa* are the dominant species harvested in Ca Mau province with *M. ensis* representing the highest proportion of shrimp harvested (48–50%) from July 1996 to June 1997. The predominance of metapenaeids such as *M. ensis* is typical of riverine mangrove habitats in Australia and SE Asia (Robertson and Duke, 1987; Primavera, 1998b) and is a reflection of wild seed recruitment from mangrove-lined waterways in the region. Metapenaeids are relatively small, low-value shrimp compared with other penaeids and this fundamentally limits the income potential of mixed shrimp–mangrove forestry farms in Ca Mau province. Their mean size at harvest of 49.7–50.6 mm is considerably smaller than the larger, higher-value *P. indicus*, which is harvested at 65 mm. Nevertheless, although a maximum size of 130–160 and 190–230 mm can be attained in offshore marine environments by adult metapenaeids and *P. indicus*, respectively (Grey et al., 1983), it is unlikely that this would be achieved in the brackishwater ponds in Ca Mau province. Continued reliance on low-value metapenaeids, which represent up to 85% of total harvest, will prevent increases in yields beyond that of the already successful farmers. For shrimp yields to increase markedly, farmers should consider stocking hatchery-reared *P. monodon* as it is a large, high-value shrimp species (potential harvest size of 100–150 mm or 50–80 g), within an improved extensive farming framework. However, at present, the quality of hatchery-reared postlarvae is poor and farmer expertise is low in Vietnam. These issues need to be addressed before hatchery-reared stocking is feasible in Ca Mau province.

Prior to 1993, *P. indicus* was the dominant species cultured and fished in Ca Mau province. The situation has changed drastically over the past few years with this species representing only 6.7–9.7% of the total species harvested between July 1996 and June 1997. Contributing factors for the decline of *P. indicus* may include White Spot disease outbreaks, over-exploitation of *P. indicus* wild stock by fishers and farmers, and the disappearance of shrimp nursery grounds due to the loss of mangrove forest habitat in Ca Mau province (de Graaf and Xuan, 1998; Phuong and Hai, 1998). This reversal in species dominance is closely linked to the decline in yields over recent years as *P. indicus* is a larger higher-value shrimp compared with that of metapenaeids. The abundance of *P. indicus* increased between February and May instead of during the traditional ''Mua'' harvest season between September and February (Binh and Lin, 1995) due to a late wet season in 1996. The increase in proportion of *P. indicus* from February to May (up to 28.3% of total harvest) is linked to the higher yields reported by farmers at this time of year, as this species is larger (by approximately 15 mm) and generates greater profits than metapenaeids.

5. Conclusions

Poor and highly variable recruitment of wild seed (Johnston et al., 2000) and suboptimal water quality in local waterways indicate that it will be difficult to vastly improve shrimp yields in Ca Mau province. Nevertheless, there is a small proportion of highly successful farmers, who experience the same limitations on recruitment and water quality as unsuccessful farmers, indicating that improvements to management techniques and pond design may be the most important factors in increasing overall yields to these levels. Therefore, through appropriate extension and careful application of techniques by farmers, it should be possible to improve mean yields from wild stock up to double the existing levels within an extensive and sustainable farming framework. It is believed that adoption of a separate silvofisheries farming model will allow farmers greater control over management techniques as well as improve water quality and reduce pond bottom fouling. Careful control would, however, be needed to ensure encroachment of ponds into mangroves does not occur with the adoption of this model. A comprehensive socio-economic analysis is required to validate whether separate farms generate higher shrimp yields. To further increase farm production and reduce the risks associated with shrimp culture, diversification into other income generating practices (secondary fisheries products and cash crops) is necessary. Stocking hatchery-reared *P. monodon* postlarvae within an improved extensive farming framework (in a localised area of the pond with some supplemental feeding), should improve shrimp yields and income based on their larger size and higher market value than metapenaeids (Johnston et al., 1999). However, before the latter can be adopted, the current state of hatcheries in Vietnam needs to be addressed in order to improve postlarval quality, as it is unacceptable at present, and care is needed to ensure the carrying capacity of the ponds is not exceeded.

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