Shrimp seed recruitment in mixed shrimp and mangrove forestry farms in Ca Mau Province, Southern Vietnam

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Abstract

The densities of shrimp seed recruited into ponds at mixed shrimp and mangrove forestry farms in Ca Mau province, southern Vietnam, were monitored semi-continuously from 1996 to 1998 to determine whether shrimp culture in the region is recruitment-limited. The numbers of shrimp seed lost during harvests were also monitored to assess whether current management strategies contribute to low stocking densities and pond production. Shrimp seed recruitment densities were low and highly variable with farms recruiting less than 1 postlarva m$^{-3}$ between August 1996 and May 1997. Recruitment varied significantly with season ($P = 0.0014$), with peaks in October to November and April to May, the former having the highest recruitment densities. This trend is consistent with seasonal offshore spawning events in southern Vietnam. Recruitment did not vary significantly between day and night ($P = 0.8$), although data suggest that recruitment may be higher at night during peak recruitment months November, February. Postlarval densities were significantly higher on the first day (24 h) of each spring tide period ($P = 0.0046$). Mean total length of shrimp seed was 13.72 ± 0.35 mm, which indicates that farms are recruiting postlarvae approximately 15–20 days post-metamorphosis (PL$_{15–20}$), or 35 days post-hatch, into ponds. Recruitment densities were higher at farms on rivers than at farms on small canals during March/April 1998, which corresponded with peaks in immigration of postlarvae into estuaries on tidal currents at this time. The numbers of shrimp seed lost during harvests were high, reducing net recruitment and net stocking densities to 0.15 postlarvae m$^{-2}$ from a potential gross stocking density of 0.35 postlarvae m$^{-2}$. Shrimp culture in Ca Mau province is recruitment-
limited. This is a major factor contributing to low shrimp yields in the region. Current harvesting techniques need to be modified to reduce postlarval losses and improve overall stocking densities and pond production. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The rapid expansion of shrimp aquaculture in Vietnam over the past 15 years has resulted in its emergence as one of the largest shrimp farming nations in southeast Asia, based on land area. The Mekong Delta is by far the most productive area for brackishwater aquaculture and freshwater fisheries, representing 67% of Vietnam’s total aquaculture and freshwater fisheries production from an area of 301,352 ha (Lovatelli, 1997). Brackishwater aquaculture alone has increased from 48,700 ha in 1985 to 237,739 ha in 1994, which is equivalent to a 388% increase in land area (Lovatelli, 1997).

Although the rising importance of shrimp aquaculture in Vietnam has brought considerable financial benefits to the local communities, the rapid, and to a large extent, uncontrolled increase in pond area has contributed to considerable loss of mangrove forests and environmental degradation in the Mekong Delta. This loss has been particularly severe in the former Minh Hai province where rates of forest clearance have been estimated at up to 5000 ha year\(^{-1}\), with less than half the original forest area (\(< 50,000\) ha) remaining in 1992 (Hong and San, 1993). Mangrove clearance has been driven by a number of factors, the most devastating of which being pressure for firewood and construction poles, and shrimp culture expansion. The decline in forest area has threatened supplies of firewood and construction materials, and has led to declines in plankton and shrimp seed densities, salt-water intrusion, accelerated coastal erosion, production of pyrites and reduced biodiversity (Sinh, 1994; Hong, 1996). To ease the land use conflict between mangrove silviculture and shrimp aquaculture, State Forestry–Fisheries Enterprises (SFFEs) were established where shrimp are cultured together with mangroves in integrated farming systems (Johnston et al., 1999). Shrimp culture was promoted for short-term revenue, while mangrove silviculture was a long-term income-generating activity.

Although the establishment of SFFEs has slowed the rate of coastal degradation, shrimp yields have declined to 100–600 kg ha\(^{-1}\) year\(^{-1}\) in recent years due to a combination of disease outbreaks, recruitment failure, and poor farm design and management techniques (Binh and Lin, 1995; Binh et al., 1997; de Graaf and Xuan, 1998; Johnston et al., 1999). Although recruitment failure is most likely to be associated with a decline in shrimp seed densities through the loss of nursery grounds and overfishing of wild broodstock, there are currently no data to support this hypothesis. Large fluctuations in annual yields of many penaeid shrimp fisheries have also been associated with inter-annual variations in postlarval immigration into tidal estuaries (Edwards, 1978; Rothschild and Brunenmeister, 1984; Staples and Vance, 1985).

As part of a 3-year collaborative project to determine the factors responsible for poor and declining shrimp yields in Ca Mau province, this study documents recruitment
densities of shrimp seed at mixed shrimp and mangrove forestry farms to determine whether shrimp culture in the region is recruitment-limited. Differences in postlarval densities over (a) time, (b) between farms, (c) between farm locations, (d) between day and night spring tides, and (e) consecutive days in a recruitment period are presented. Postlarval losses during harvests were also documented to determine whether the current management technique of harvesting ponds on the ebb tide directly after recruitment on the flood tide contributes to low stocking densities and pond production.

2. Methods

2.1. Study site and farming techniques

Ca Mau province is the southern-most province of the Mekong Delta, situated on the Ca Mau peninsula (Fig. 1). Research was conducted in two SFFEs in Ca Mau province: Tam Giang 3 and 184, which were established in 1987 and cover 3300 ha and 6475 ha, respectively. Enterprise Tam Giang 3 has 236 households and a population of 1007, whereas enterprise 184 has 1018 households and a population of 7000 (1996 data). For logistical reasons, postlarval recruitment was only monitored at farms in Tam Giang 3 (Fig. 1).

The majority of mixed shrimp and mangrove forestry farms in Ca Mau province are extensive, relying almost entirely on tidal recruitment of wild shrimp seed from canals and rivers to stock ponds. Farms generally have a single sluice gate situated on the waterway through which shrimp are recruited and harvested, and water is exchanged (refer to Johnston et al., 1999). Every 15 days, recruitment and harvest occur on consecutive flood and ebb tides for 4 to 5 days and nights of the spring tide period. On the flood tide, the sluice gate is opened for 3–6 h and postlarvae, juvenile and adult shrimp swim into the pond. Following recruitment, the sluice gate is closed. Once the tide turns, the gate is reopened and the pond drained on the ebb tide with shrimp harvested in a bag net positioned at the back of the sluice gate. Following recruitment and harvesting, the sluice gate is closed for a 10- to 12-day growout period. During this period there is little or no water exchange. This 15-day growout cycle continues through the year except during periods of pond preparation and excavation (Johnston et al., 1999).

2.2. Postlarval recruitment

Two farms (12 and 23) were sampled simultaneously during one recruitment (spring tide) period per month from August 1996 to May 1997 (Fig. 2). Farm 12 is situated on Rach Ba Bon, a tidal channel leading into Song Dam Chim, whereas Farm 23 is located on Song Dam Doi 400 m upstream from its intersection with Song Dam Chim. Sampling occurred on 3–4 consecutive days and nights over each spring tide period with 3 × 15 min replicate sampling times taken during each flood tide. Sampling occurred approximately 15–30 min after the flood tide commenced (following low tide), which coincided with the period of highest recruitment into ponds according to anecdotal evidence by
local farmers. Sampling during the first third of the flood tide ensured the greatest catchability of shrimp seed and enabled long term comparisons of shrimp seed abundance (Vance, 1992; Vance and Staples, 1992). A small (48 cm mouth diameter) 500 μm plankton net was placed at the sluice gate mouth to capture a sub-sample of postlarvae (shrimp seed) entering the pond. The small mouth diameter was chosen so that our sampling regime did not significantly reduce recruitment into the ponds, which was of concern to farmers. Postlarvae were fixed in 4% seawater formalin and counted. If numbers were high, a sub-sample by weight was counted. A flow meter (pre-calibrated)
was attached at the mouth of each net to calculate the volume of water sampled during each 15 min replicate to determine postlarval density. Shrimp were separated into families with those belonging to family Penaeidae included as recruited shrimp, whereas sergestids (*Acetes* species) and palaemonids (*Macrobrachium* species) were excluded. Postlarvae were not identified further due to a lack of resources, although detailed species identification was conducted on shrimp harvests. Greater than 80% of cultured shrimp from mixed shrimp–mangrove forestry farms in Ca Mau province are *Metape- naeus ensis* and *M. lysianassa* and approximately 10% are *Penaeus indicus* (Johnston et al., 2000, in press). Shrimp size (total length = rostrum tip to telson tip) was recorded from each time replicate of consecutive day and night spring tide samples during each recruitment period.

To ascertain whether shrimp seed were lost during harvests, a preliminary check was conducted by taking one sub-sample per harvest directly following each recruitment over the 3–4 day spring tide period. Postlarvae were fixed as above and the number of postlarvae counted. High losses dictated that a more rigorous sampling design be applied as is described in Section 2.3.
2.3. Postlarval recruitment and losses at farms on rivers vs. inner canals

Enterprise Tam Giang 3 has a network of rivers and constructed canals from which smaller canals extend. Farms are dispersed along these rivers and smaller canals. In an attempt to explain preliminary trends of higher shrimp yields at farms on large canals and rivers compared with farms on small inner canals, an investigation into possible differences in seed recruitment between the two locations was conducted. The primary objective of this study was to determine whether seed recruitment was lower at farms on small, inner canals than at farms on rivers, and to accurately determine postlarval losses during harvest and to what extent they impact on overall stocking density.

Three replicate farms were chosen on the river/main canals (farms 12, 23, 24) and three on small inner canals (farms 11, 20, 21) in enterprise Tam Giang 3 (Fig. 2). Farms were replicated at the two extremes of location (not in mid-size canals) to maximise the chance of detecting an effect due to location. Prior to the experiment, pond surface area was measured at each of the farms for pond volume calculations.

All farms were sampled simultaneously during three consecutive recruitment periods in December 1997–January 1998 (low recruitment period) and again in March–April 1998 (high recruitment period) using the technique described above. The high recruitment period coincides with peak spawning during February–March in the coastal waters of the Mekong Delta, whereas the low recruitment period occurs several months after a second spawning peak in July–August (Binh and Lin, 1995). Sampling occurred on 3 consecutive days and nights over each spring tide with $2 \times 15$ min sampling times as replicates. The total number of hours over which water entered the pond during each

![Figure 3](image_url)  
Fig. 3. Variation in postlarval recruitment at farms 12 and 23 (see Fig. 2) from August 1996–May 1997. Data points between August 1996 and February 1997 are means $\pm$ 1SE of recruitment over three to four day and night samples per month at farms 12 and 23. Data points for April and May 1997 are means $\pm$ 1SE of recruitment over two night samples per month at both farms and were not included in the statistical analysis. Data were not available for December 1996 and March 1997.
recruitment time was recorded. A measuring staff was used to estimate the depth of pond water prior to and following recruitment. This difference in water depth was used with pond surface area to calculate the total pond water volume recruited. The total number of postlarvae (PLs) recruited into the pond was calculated using the formula:

\[
\text{Pond surface area (m}^2) \times \text{difference in pond depth (m)} = \text{total pond water volume recruited (m}^3) \]

\[
\text{Total pond volume recruited (m}^3) \times \text{mean PL density (no. m}^{-3}) = \text{total number PL recruited} \]

Postlarval losses during harvest were monitored. During each outgoing tide, two 15 min time replicates were taken and the number of PL counted. The number of hours over which water flowed from the pond during each harvest time was recorded as well as the water depth of the pond before and after each harvest. The above equations were

![Fig. 4. Variation in day and night postlarval recruitment at shrimp farms 12 (A) and 23 (B) (see Fig. 2) from August 1996–May 1997. Data points between August 1996 and February 1997 are means of 3×15 min replicates per day/night. Data points for April and May 1997 are means ±1SE of 3×15 min replicates per night and were not included in the statistical analysis. Data were not available for December 1996 and March 1997.](image-url)
used to calculate the total pond water volume lost during harvest and the total number of postlarvae lost. From these values, net recruitment of postlarvae into the pond was determined by the equation:

\[
\text{Total number PL recruited} - \text{total number PL lost} = \text{net PL recruited}
\]

The total number of postlarvae recruited and lost per 15-day growout cycle was used to calculate gross and net stocking densities at each farm.

2.4. Statistical analysis

Significant differences in postlarval recruitment densities between farms, months, day/night spring tides and consecutive dates within a recruitment period were determined by repeated measures analysis (split-split plot) (Sokal and Rohlf, 1995). A t-test was used to determine whether postlarval recruitment densities were significantly different between farms on rivers and those on inner canals (recruitment densities were averaged over sampling replicates, day/night and time periods; \( n = 6 \)).

3. Results

3.1. Postlarval recruitment

Shrimp seed recruitment densities were extremely low with both farms recruiting less than 1 postlarvae m\(^{-3}\) over a 10-month sampling period between August 1996 and May 1997 (Fig. 3). Recruitment varied significantly between months (\( F_{5,5} = 26.05; \ P = 0.0014 \)), with peaks in October–November and April–May, the former having the highest recruitment densities. Recruitment was lowest in August and January. Recruit-

Fig. 5. Variation in postlarval shrimp densities on consecutive sampling days of the spring tide period. Days 1, 2 and 3 are the first, second and third day of the spring tide. Data points are means ±1SE of three 15 min time replicates for day and night samples for each consecutive day of the spring tide at two farms (12 and 23) (see Fig. 2) over 6 months.
Fig. 6. Variation in mean length of shrimp postlarvae recruited at farms 12 and 23 (see Fig. 2) from July 1996–May 1997. Data points are means ± 1SE of postlarval length over day and night samples at both farms per month.

Recruitment was similar between farms 12 and 23, although farm 12 experienced much higher recruitment in November 1996 due to a substantially higher night recruitment during this month (1.864 postlarvae m⁻³). There was no significant difference between night and day recruitment densities ($F_{(1,168)} = 0.06; P = 0.8$), although data suggest that recruitment may be higher at night during peak recruitment periods (November and February) (Fig. 4). There was a significant difference in postlarval densities between consecutive days in a recruitment period ($F_{(1,168)} = 8.25; P = 0.0046$) with densities being highest on the first day of the spring tide for both farms 12 and 23 (Fig. 5).

Fig. 7. Mean total number of shrimp postlarvae recruited into ponds per 15-day growout cycles at farms on rivers (farms 12, 23, 24) vs. inner canals (farms 11, 20, 21) (see Fig. 2) during December 1997–January 1998 and March–April 1998. Data points are means ± 1SE of the sum of postlarvae recruited over 3 days and nights per springtide over three consecutive growout cycles in December–January 1997–1998 and three cycles in March–April 1998.
Mean total length of postlarvae varied between 5.31 and 27.46 mm from July 1996 to May 1997, with mean a size over the 9-month period of 13.72 ± 0.35 mm (Fig. 6). Total length was greatest in August 1996 and decreased through to February 1997, with the high value in January being due to a much larger postlarval size recruited at farm 23.

3.2. Postlarval recruitment and losses at farms on rivers vs. inner canals

Recruitment densities did not vary significantly between farms located on small inner canals vs. those on rivers ($P = 0.4$), with mean postlarval densities at farms on rivers and small inner canals being 0.137 ± 0.02 and 0.119 ± 0.02 postlarvae m$^{-3}$, respectively. An exception was higher recruitment at farms on rivers during March/April 1998, which corresponded with peaks in immigration of postlarvae into estuaries on tidal currents at this time (Fig. 7).

![Graph showing recruitment and losses at farms on rivers vs. inner canals](image)

Fig. 8. Mean total number of shrimp postlarvae recruited and lost during consecutive recruitment and harvest cycles during December–January 1997–1998 (A) and March–April 1998 (B) at farms on inner canals vs. rivers. Total postlarvae (PL) numbers for each farm were calculated over three day and night recruitments/harvests and averaged over three consecutive growout cycles in each time period.
Total numbers of postlarvae recruited into the six ponds (based on 3 days and nights) per 15-day growout cycle in December–January 1997–1998 and March–April 1998 varied between 653 and 8020 (Fig. 8). These numbers equate to gross stocking densities ranging between 0.01–1.6 postlarvae m$^{-2}$, with an overall mean of 0.35 ± 0.09 postlarvae m$^{-2}$. Postlarval losses, however, during harvests were significant and were often greater than the total number of postlarvae recruited, resulting in net losses from the ponds (Fig. 8). During harvests, farm 23, in particular, had consistently higher numbers of postlarvae lost than were recruited (Fig. 8). When taking these losses into consideration, net stocking densities at the six farms were considerably lower than gross stocking densities, being 0–0.5 postlarvae m$^{-2}$ with a mean of 0.13 ± 0.04 postlarvae m$^{-2}$.

4. Discussion

Poor and highly variable recruitment of shrimp seed into ponds indicates that shrimp aquaculture in Ca Mau province is recruitment-limited. Assuming that the majority of postlarvae recruited are metapenaeids (Johnston et al., in press), postlarval densities in Song Bo De estuary (0.05–1.8 postlarvae m$^{-3}$) are considerably lower than Meta-penaeid spp. densities reported in comparable mangrove estuaries (1.8–9.1 postlarvae m$^{-3}$) (Goswami and Goswami, 1992). Low seed densities, recorded over the 10-month sampling period between August 1996 and April 1998, are most likely to be a key factor contributing to poor and declining shrimp yields in the province in recent years. Low densities coupled with high postlarval losses during harvests indicate that reliance on wild stock is not sustainable and that current management practices are not optimising production.

Very little accurate information is available on postlarval densities in the Mekong Delta and widely varying techniques and small-scale heterogeneity make comparisons between studies at various locations in the Delta difficult. This study is the first to document postlarval recruitment densities into mixed shrimp and mangrove forest farms in tidal channels within Song Bo De estuary, Ca Mau province. Recruitment densities ranging between 0.05 and 1.8 postlarvae m$^{-3}$ at farms in enterprise Tam Giang 3, are consistent with postlarval densities of 0.4 m$^{-3}$ reported in a tidal channel southwest of Bo De River at Nam Can, May 1987 (Vu Do Quynh, unpubl. data). Both sampling sites are geographically close to one another and have experienced extensive mangrove clearance since the mid 1980s due to the rapid expansion of shrimp culture. In contrast, shrimp seed densities in a small tidal channel in Cuu Long province, May 1987, were considerably higher at 27 postlarvae m$^{-3}$ (Vu Do Quynh, unpubl. data). Although insufficient data on postlarval densities are available prior to the expansion of shrimp culture in the Mekong Delta, it is well-recognised that seed numbers have declined in recent years. Postlarval densities documented in this study are the first to be reported since the rapid expansion of shrimp culture and they appear to support the trend of declining numbers of shrimp seed in local waterways in Ca Mau province. There are a number of reasons for this trend, the most obvious of which is the loss of nursery grounds through extensive clearance of mangrove forests due to shrimp culture expan-
sion, overexploitation by traditional users for wood products, illegal immigration and urbanisation (Primavera, 1995; Hong, 1996; Macintosh, 1996). The importance of mangroves as nursery grounds and a habitat for shrimp and other fisheries resources has been widely documented (Roberston and Duke, 1987; Vance et al., 1990; Chong et al., 1996; Primavera, 1998). Other reasons for the decline in postlarval densities in Ca Mau province include a reduction in wild broodstock numbers due to repeated outbreaks of White Spot disease since 1994 and increasing fishing pressure (de Graaf and Xuan, 1998). Poor water quality and increasing pollution from sewerage, agricultural fertilisers and pesticides have also contributed to localised reductions in seed densities in Ca Mau province (Johnston et al., unpubl. data).

In the majority of shrimp recruitment studies that have been documented, there is an underlying pattern of two main periods of spawning and immigration of penaeid postlarvae into mangrove estuaries each year: although local conditions modify this pattern so that either one of the peaks is dominant (Staples and Vance, 1985). Seasonal peaks in shrimp seed recruitment during October–November and April–May in Ca Mau province are consistent with immigration pulses of postlarvae of *P. merguiensis* into mangrove estuaries in Northern Australia (Staples, 1979, 1980; Staples and Vance, 1985) and Goa, India (Goswami and George, 1978) and immigration of several shrimp species to mangrove estuaries in the Philippines (Motoh, 1981; Primavera, 1998). The largest recruitment pulse in Song Bo De estuary, Ca Mau province, during the post-monsoon months of October–November is consistent with immigration into the northeastern gulf of Carpentaria (March–May) (Staples, 1979) and mangrove estuaries in the Philippines (October–November) (Motoh, 1981). Recruitment peaks in Song Bo De estuary correspond with wild stock spawning events in the Mekong Delta, which occur in July–August and February–March of each year (Binh et al., 1997). The larger recruitment peak in October–November is consistent with the larger spawning event at this time for wild stock penaeids in Australian, Indonesian and Thai waters (Staples, 1989). Recruitment peaks lag 1–2 months behind spawning events in the Delta as postlarvae must first migrate into the estuaries from offshore spawning grounds. This is consistent with the mean total length of shrimp seed recruited into shrimp ponds of 13.72 mm, which indicates they are approximately 15–20 days post-metamorphosis (PL<sub>15–20</sub>) and approximately 35 days post-hatch (Wyban and Sweeney, 1991). Postlarvae of *P. merguiensis* in Australian estuaries have a bi-modal size distribution throughout the year with a greater length in October–November and March–April (Staples and Vance, 1985). This is not the case for shrimp larvae in Song Bo De estuary, although it should be noted that trends for a particular species were not determined.

Immigration of penaeid larvae into mangrove estuaries is greatest during spring tide periods (Staples and Vance, 1985; Vance and Staples, 1992), and is the basis for recruitment/harvesting strategies adopted by farmers in Ca Mau province. Higher densities of postlarval recruits during the first day of each spring tide period at farms in Ca Mau province is most likely to be associated with maximum tidal currents, as greatest postlarval immigration into mangrove estuaries in the Gulf of Carpentaria, Australia, occurred at these times (Staples and Vance, 1985). Most immigration to nursery areas in Moreton Bay, Australia, was also found to be completed in the first 3 h of the 6 h flood tide, with numbers declining as water velocity reached a maximum
Both these trends in larval immigration have implications for recruitment strategies. Farmers should concentrate their efforts during the initial days of each spring tide period and accommodate changes in tidal currents during each flood tide to maximise recruitment into the pond. In particular, it is critical that recruitment of larvae occurs prior to maximum water velocity during flood tides to minimise damage and maximise survival during growout. This factor has been incorporated in recruitment techniques by successful farmers (Johnston et al., 1999). Despite no significant difference in day and night recruitment into ponds, other studies have documented greater immigration into mangrove estuaries at night (Edwards, 1978; Garcia and Le Reste, 1981), and greater activity of shrimp at night (Vance, 1992; Vance and Staples, 1992). Several factors such as tidal cycles, moon phase, rainfall, temperature and nutrient levels affect shrimp activity, and are likely to have contributed to marked variation in recruitment densities between days and nights recorded in this study. Nevertheless, it seems that recruitment may be higher at night during periods of peak wild seed recruitment (February and November) and further investigation of day–night recruitment over a longer period is required. These variations in wild seed densities should be considered in management strategies with farmers maximising recruitment efforts during night-time spring tides, particularly during peak recruitment periods to optimise stocking density in ponds.

Hydrodynamic studies in mangrove creeks have shown that tidal amplitude decreases and water residence time increases in long small waterways (Wolanski et al., 1980; Wolanski, 1992; Ridd et al., 1998). Hence, it was expected that seed recruitment at farms on inner canals would be lower than at farms on large rivers, as the extent of postlarval migration is dependent on tidal flow. Farms on rivers benefit from greater access to postlarvae through greater tidal currents at these times, whereas those on inner canals with reduced tidal flow suffer. Trends in postlarval recruitment with farm location were not consistent over the two time periods sampled. Several factors influence recruitment such as management technique, small-scale variability in the hydrodynamic conditions surrounding individual farms and prevailing environmental conditions. Recruitment was higher at farms on rivers compared to farms on canals in March–April 1998, reflecting migration of postlarvae on tidal currents from offshore waters following spawning at this time. It is possible that the importance of farm location for recruitment increases during periods of larval immigration following spawning. This hypothesis needs to be tested over several recruitment seasons before the effect of farm location can be validated. Furthermore, higher recruitment in December–January than March–April (Fig. 7) is inconsistent with spawning patterns in the Mekong Delta (Binh and Lin, 1995), highlighting interannual variation and the need for sampling over several seasons to elucidate consistent trends.

High losses of recruited postlarvae during harvests demonstrates that current management strategies of recruitment and harvesting on consecutive flood and ebb tides are contributing to poor shrimp yields in Ca Mau province and subsequently need to be modified in order to maximise production. These losses have reduced net recruitment into ponds, with gross stocking densities of 0.35 postlarvae m$^{-2}$ and net stocking densities of 0.15 postlarvae m$^{-2}$ being considerably lower than other extensive culture systems that are viable. These low stocking densities are reflected in the considerably
lower shrimp yields of farms in this region (mean of 286 kg ha\(^{-1}\) year\(^{-1}\)) compared with "extensive" farming systems in other countries such as the Philippines which have yields of 600–1300 kg ha\(^{-1}\) year\(^{-1}\) (Primavera, 1991, 1993). It must be noted, however, that juvenile and adult shrimp remain in ponds for up to 4 months prior to harvest, so stocking densities at any one time are likely to be higher than these figures suggest. Stocking densities during peak recruitment times will also be higher as demonstrated at farm 12 and 23 where mean gross stocking densities in April/May 1997 were 1.5 and 1.6 postlarvae m\(^{-2}\). The fact that farm 23 consistently had higher postlarval losses during harvest than any other farm suggests that the management technique of individual farmers plays an important role in reducing postlarval loss. Examples of modified management strategies that are likely to reduce postlarval losses during harvest include continual recruitment over 1–2 months followed by a single complete drain harvest or specialised harvesting techniques, such as the "against water current technique", instead of the traditional bag net (refer to Johnston et al., 1999). The "against water current technique" removes only the larger shrimp during harvest, while at the same time allowing larvae to enter the ponds to maximise stocking densities. Recommendations will be presented to farmers in the extension phase of this project together with on-farm trials. If modifications to harvesting practices are adopted, stocking densities and annual yields may improve.

5. Conclusion and recommendations

Shrimp yields for mixed shrimp and mangrove forestry farms in Ca Mau province will remain low and unsustainable with continued reliance on wild seed for stocking ponds. In the longer term, mangrove forest losses need to be minimised relative to rates of reforestation, and limits should be placed on fishing practices (mesh sizes, quotas) to sustain nursery grounds and improve wild stock numbers. Shorter term increases in production with regard to recruitment lie in improvements to management strategies, particularly harvest techniques. Stocking hatchery-reared postlarvae of \(P.\ monodon\) throughout the 1990s had devastating consequences for the majority of farmers, due to disease outbreaks and inappropriate management techniques (de Graaf and Xuan, 1998). Many farmers remain in debt, with culture of \(P.\ monodon\) considered to be risky due to continuing disease problems in hatchery-reared postlarvae. Nevertheless, for shrimp yields to increase, adoption of improved extensive culture needs to be considered. This will involve low stocking densities of hatchery-reared larvae (\(P.\ monodon\) or \(P.\ indicus\)) with minimal supplemental feeding, together with farmer training in appropriate culture techniques. Sustainability of shrimp aquaculture in Ca Mau province is dependent on both enhancing wild stocks and addressing hatchery-reared stocking issues, particularly improvements in the quality of hatchery-reared postlarvae.

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