Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues

Editors: Nigel Preston and Helena Clayton

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Contents

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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Preface

In the coastal areas of the Mekong Delta the extensive tidal incursion of seawater during the dry season increases the salinity in the lower reaches of the Delta. This saline intrusion means that agricultural crops, including rice, cannot be grown during the dry season. Over the past 30 to 40 years many rice farmers in the saline affected areas have adapted to the natural conditions by growing rice in the wet season, then using the rice fields for growing shrimp in the dry season. This farming practice, known as the rice–shrimp system, has allowed farmers to generate a source of income that was not previously possible in the dry season.

The adoption of the rice–shrimp system in the Mekong Delta has increased substantially over the past two decades with around 40,000 ha under production in 2000. By the mid 1990s concerns were being raised about the environmental and economic sustainability of the rice–shrimp system. These concerns included land loss through sedimentation, salinisation of rice growing areas, shortages of shrimp postlarvae (seedstock), and the financial implications of widespread crop mortalities. These issues, coupled with the poor environmental performance on shrimp farming elsewhere in Asia, meant that the scale and speed of the adoption of the rice–shrimp farming practice was of increasing interest to local policy makers and scientists. In 1997, after a request from the Vietnamese government, the Australian Centre for International Agricultural Research commissioned an interdisciplinary research project to investigate these sustainability concerns. The project was designed to address the biophysical and socioeconomic issues surrounding rice–shrimp farming in the Mekong Delta. The research focused on developing a better definition of the farming system and of the factors that impact on its sustainability. The aim was to identify farm management and policy options for improving the sustainability of the system. The multidisciplinary project included economic farm surveys, resource surveys, bioeconomic analysis, analysis of the rice and shrimp production environments and controlled field experiments.

The papers presented in this report are the proceedings of the project's final review workshop, held in December 2000 at Can Tho University, Vietnam. The twelve papers describe the results of the various components of the project. The first two chapters provide an overview of the research components and the socioeconomic characteristics of rice–shrimp farms in the study region. Chapters 3 to 5 examine the key factors influencing the sustainability of the shrimp production cycle; the growth and survival of shrimp in relation to physical conditions in the rice–shrimp production ponds; shrimp diet and shrimp hatchery production. Chapters 6 to 9 focus on the rice production system including: the suitability of different rice varieties for use in the rice–shrimp system; salinity dynamics and cropping; the response of rice to the timing of salinity stress and the application of a simulation model to quantify the response of rice to salinity stress and to quantify the yield variability in response to different sowing dates.

In chapters 10 and 11 observations from a bioeconomic model of the rice–shrimp system are examined in relation to factors affecting farm financial risk and the loss of rice–shrimp land due to sedimentation. The final chapter (12) examines the suitability of land under different farming practices, particularly rice–shrimp farming, and recommendations are made for land use planning including zoning areas as suitable only for rice–shrimp farming. An appendix to the study summarises the best management practices for the shrimp farming component and these practices have been

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ACIAR Technical Reports No. 52e
(printed version published in 2003)

incorporated into an extension video and CD-ROM that has been widely distributed to farmers and extension officers in the region.

The results of this study have provided new insights into the key factors affecting the sustainability of rice–shrimp farming in the Mekong Delta. The integration of dry season shrimp farming into rice fields has raised incomes for many farmers in the region over several consecutive seasons. However, a number of key constraints still need to be addressed in order improve the environmental and economic sustainability of this system. The study revealed that the traditional practice of recruiting native shrimp is not sustainable because of the loss of land from pond sedimentation due to the high water exchange required for natural recruitment. The more recently developed system of stocking with hatchery-reared postlarvae combined with low water exchange is promising, but limited by the availability of healthy postlarvae and episodic outbreaks of disease. The current lack of investment in technology for improved health screening and domesticated postlarval production techniques are critical constraints to the sustainability of all forms of shrimp farming, including rice–shrimp farming, in the Mekong Delta region.

The study showed that, even with current poor shrimp survival rates, many rice–shrimp farmers are managing their financial risks well by maintaining a generally high level of income diversification at the household level. This diversification of income means that farm households have alternative sources of income in the event of high shrimp mortality. Moreover, the farming system allows for the production of rice and other staple items for household consumption, further insuring against the risks associated with shrimp production. The results of the study indicate that rice yields are not adversely affected by using the same fields for shrimp production. Heavy rains at the beginning of the wet season effectively leach salts in the rice–shrimp fields. There was no evidence of a long term build up in salts or that soil salinisation from shrimp culture adversely affects subsequent rice yields. However, the study has resulted in recommendations about the most appropriate rice varieties to use and the timing of rice planting in the rice–shrimp system.

An emerging sustainability issue is the trend towards intensification. As rice–shrimp farmers are becoming more experienced they have tended to intensify their practices. Some farmers are abandoning the rice crop cycle and transforming their rice–shrimp polders into conventional shrimp ponds. Concern over the environmental implications and financial risks of more intensive monoculture systems has induced local policy makers to try to regulate land practices. In some areas land has been zoned as suitable only for integrated rice–shrimp farms. The results of this study have indicated that the rice–shrimp system is a more ecologically and economically sustainable approach than intensive shrimp monoculture, particularly in the low land areas of the study region that are affected by daily tidal flooding in the later part of the year. As detailed in the final chapter of this study, the implementation of zoning of land as suitable only for rice–shrimp farms, together with the adoption of the recommended improvements of rice–shrimp farming practices, should significantly improve the economic and environmental sustainability of rice–shrimp farming in the Mekong Delta.

Further details about the project research are provided at the following websites: http://www.reap.com.au/RiceShrimp.htm
http://www.enaca.org/Shrimp/Consortium.htm##Case Studies - Asia-Pacific Region

CHAPTER 1

An overview of the project research

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RICE–SHRIMP farming started in the Mekong Delta in Vietnam around 30 to 40 years ago. The integration of a shrimp production cycle into the traditional rice monoculture farming system is an innovation that has been driven by resource conditions in the Delta. Severe saline intrusion occurs during the dry season in the waterways of the Delta, and rice-growing farms in coastal regions are limited to a single rainy season rice crop. These saline areas are illustrated in Figure 1.

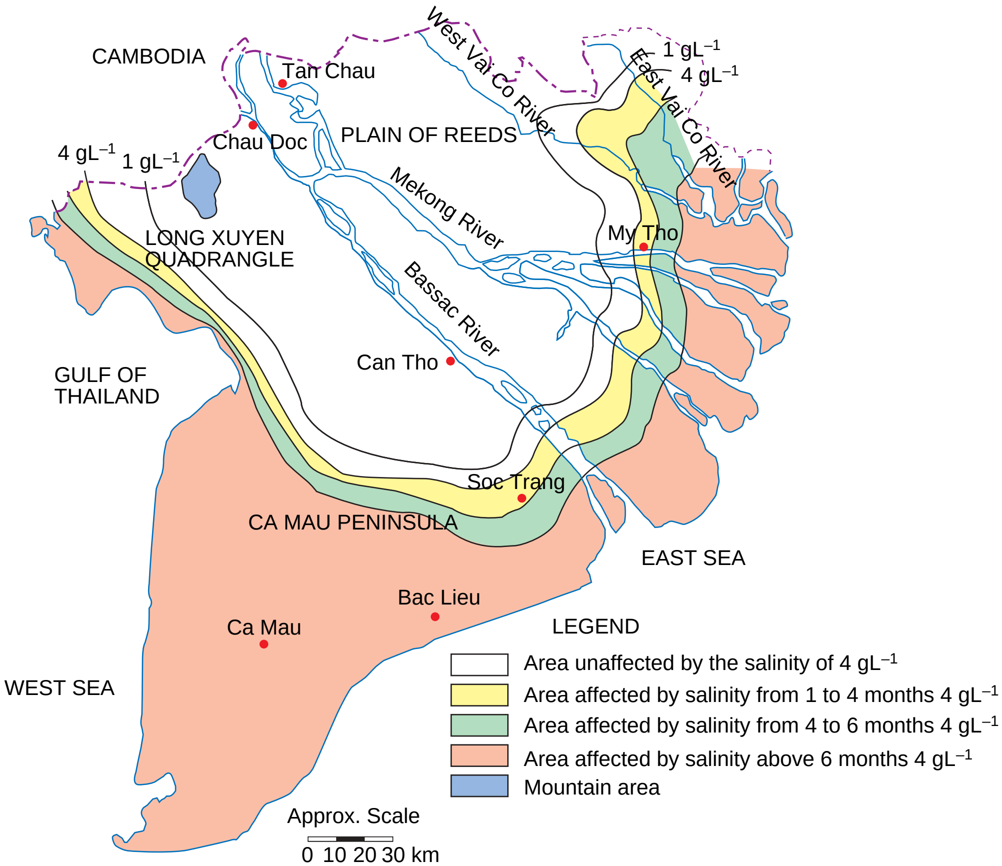

Figure 1. The incidence and severity of saline intrusion in the Mekong Delta, Vietnam.

By redesigning the rice field to include a deep wide trench around the periphery, farmers are able to establish water-holding ditches suitable for shrimp culture in the dry season. By flooding the field with brackish water from nearby canals at the commencement of the dry season, farmers

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

are able to raise shrimp. Traditionally by practising frequent tidal water exchange, farmers have been able to capture naturally abundant shrimp postlarvae (largely *Penaeus merguiensis*, *P. indicus* and *Metapenaeus ensis)* in the field and raise them to a harvestable size. At the start of the rainy season, farmers rely on the heavy monsoon rains to flush the salts out of the system before planting the wet season rice crop. The typical layout of a rice–shrimp system is shown in Figure 2. While the redesign of the rice field into a rice–shrimp polder does involve sacrificing some rice-growing area, the adoption of the dry season shrimp crop has generally raised farm household incomes.

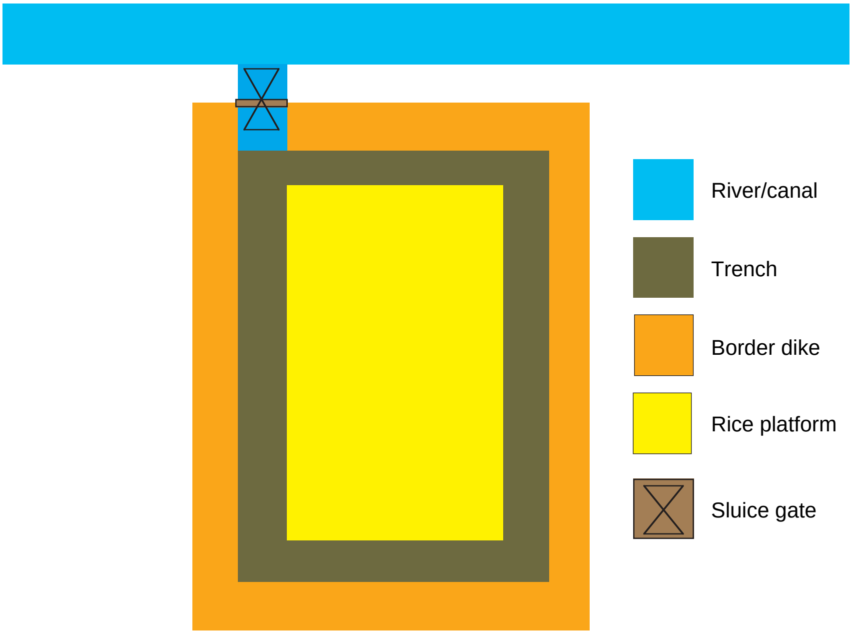

Figure 2. Typical layout of the rice–shrimp polder.

Over time, farmers have adapted the rice–shrimp system and now two major types of practices are evident. The traditional practice of recruiting natural shrimp has continued in some areas, whereas in other regions farmers have now adopted a more capital-intensive style, based on the purchase of hatchery-reared *P. monodon* species and the addition of purchased feed and other pond inputs.

The adoption of rice–shrimp farming in the Mekong Delta has increased substantially since the 1980s. For example, in My Xuyen district the total area under rice–shrimp culture increased from 500 ha in 1982 to 6635 ha in 1988. By the mid-1990s there was anecdotal evidence of a number of sustainability issues surrounding the rice–shrimp system. These issues included land loss through sedimentation, salinisation of rice-growing areas, shortages of shrimp seedstock and the financial implications of widespread crop mortality. Coupled with the poor environmental performance of shrimp farming elsewhere in Asia, these problems meant that the scale and speed of the adoption of the rice–shrimp farming practice was of great concern to local policy makers and scientists. In 1997, after a request from the Vietnamese government, the Australian Centre for International Agricultural Research commissioned an interdisciplinary research project to

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

investigate these sustainability concerns. The results of this research project are reported in this volume.

The research project and study region

The research project was designed to cover the biophysical and socioeconomic issues surrounding rice–shrimp farming, and to identify farm management and policy options for improving the sustainability of the system. Four main sub-projects were undertaken: socioeconomic and physical resources characterisation and analysis; investigation of the rice-growing phase of the system, with particular emphasis on salinity issues; and investigation of the shrimp pond conditions, with emphasis on the shrimp pond environment. Bioeconomic modelling tools were then used to investigate the implications of various sustainability issues on farm household income.

Research was carried out with the cooperation and assistance of farmers and local government agencies in the provinces of Soc Trang and Bac Lieu in the southern area of the Mekong Delta. Within each of these two provinces, two districts (My Xuyen and Gia Rai) were chosen for the major research activity. A regional map of Vietnam showing the Mekong Delta and the study provinces is shown in Figure 3.

Figure 3. Regional map of Vietnam, indicating the Mekong Delta region and the ACIAR study provinces.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Sustainability concerns

Salinisation

Saline intrusion is a naturally occurring phenomenon that affects land productivity even in the absence of shrimp culture. In general, the saline intrusion problem means there is only sufficient time to grow one rice crop per year, when farmers rely principally on wet season rainfall. Farmers may also use fresh water from canals to provide supplementary irrigation where required, although in years when saline water intrusion occurs early, this option is not possible.

Two concerns regarding the potential effect of the rice–shrimp farming system on rice yields were raised during the development of the project. These were that the inundation of brackish water onto the rice fields during the dry season may lead to a build up of soil salinity over time; and that the delay in planting the rice crop under the rice–shrimp system (because of the need to flush salts from the system at the start of the rainy season) may reduce yields because of the increased risk of end-of-season salinity damage resulting from saline intrusion.

There is scant evidence on the effects of soil salinisation from shrimp culture on subsequent rice yields. While Tran et al. (1999) concluded that salt leaching into neighbouring rice fields caused significant damage to the rice fields, comparisons between rice yields in rice–shrimp and rice monoculture fields can be confounded by spatial factors affecting the choice of farming system. In a study of soil–water dynamics in rice monoculture and rice–shrimp fields, Phong et al. (this Report) observed that soil salinity was generally lower in rice–shrimp fields than in rice monoculture fields. They explained this observation in terms of the relative position of rice monoculture and rice–shrimp fields in the system. Rice–shrimp fields are generally located nearby canals and are engineered to allow effective water exchange. Farmers can take advantage of this to leach the salts from the system at the beginning of the rainy season. In contrast, the salinity that builds up in some rice monoculture fields due to capillary rise during the dry season could not be flushed away in areas that did not have good access to canal water. Phong et al. (this Report) also concluded that the heavy rains that occurred at the beginning of the wet season were effective in leaching salts in the rice–shrimp fields, and suggested that there was no long-term build-up in salts from the practice. They did, however, make recommendations about appropriate timing of rice planting for such systems, to ensure that the crop was not planted too early.

Nguyen Ngoc De et al. (this Report) report on the promising performance of new rice varieties that are short duration (115–120 day) and relatively salt tolerant. They recommended the use of MTL119, which performed better in the field trials they conducted compared to the most commonly used variety. They also noted that yields were relatively higher in the rice monoculture system compared to the rice–shrimp system, which provides contrasting evidence to the conclusions of Phong et al. about salt leaching. A possible explanation for this is the wide spatial variation in soil salinity, as reported by Phong et al.

The rapid changes in pond salinity that occur during the transition between wet and dry seasons (see Phong et al. this Report) have implications for risk management of the brackish water shrimp crops. The precise physiological tolerances to variations in salinity levels are not well understood for the species of shrimp farmed in the rice–shrimp system. In common with other *Penaeus* species, *P. monodon*, *P. merguiensis* and *P. indicus* are euyrhaline species capable of actively osmoregulating their body fluids when exposed to a wide range of external salinities (Dall et al. 1990). However, studies of osmoregulatory ability indicate that *P. monodon* has a

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

limited ability to survive in very low salinities (Ferraris et al. 1987). Field studies of the growth and survival of *P. monodon* in rice–shrimp ponds have recorded complete stock losses following rapid falls in pond salinity (Truong Hoang Minh et al. this Report). However, field observations also indicated that the *P. monodon* were infected with white spot syndrome virus, which was subsequently confirmed by PCR analysis. Whilst the precise cause of the shrimp deaths could not be determined, these observations are consistent with previous observations that rapid changes in pond salinity increase the risk of mass mortalities in shrimp ponds (Chanratchakool et al.1998).

Land degradation

The choice between tidal recruitment of wild shrimp postlarvae and 'artificial' stocking of hatchery-purchased postlarvae is critical to the problem of sedimentation-related land degradation. This is due to the differing water exchange practices between the two methods of shrimp recruitment. The technology for hatchery-based systems involves low water exchange rates, whereas tidal recruitment systems are characterised by a higher water exchange rate that is necessary for shrimp postlarvae recruitment. The frequency of water exchange is a significant factor in land loss — the exchange and inundation of turbid water throughout the shrimp-raising season results in suspended sediment settling to the floor of the rice–shrimp polder.

The build-up of sediment throughout the year in the already shallow rice–shrimp polder needs to be removed at least once per year to maintain a pond depth necessary for a healthy pond environment for culturing shrimp. Some farmers have been able to flush the sediment back into the river or canal, but due to the potential environmental impacts and canal management problems with this kind of disposal, local and provincial governments in many areas have policies that prohibit flushing. In the absence of other options, farmers have been depositing the sediment on top of existing border dikes and on non-productive land. However, as the capacity of these areas is exhausted, new dikes have been constructed on productive land (inside the polder) for the deposition of the sediment. In some areas where natural shrimp recruitment has been practised over the long term, the land loss arising from sedimentation is a very pressing issue and has important implications for the long-term productivity of land.

The advantage of the natural shrimp-based rice–shrimp system is that very little cash risk is imposed on the farmer; however, the loss of farmland draws the sustainability of the system into question (Tran et al. 1999; Clayton this Report). Clayton shows that the high water exchange natural shrimp system, which results in land degradation, may be privately optimal from the point of view of the typical Gia Rai farmer. Further analysis of the land degradation in the rice–shrimp system also demonstrated that as *P. monodon* survival improves so does the incentive for preserving farmland (Clayton 2002). This analysis highlighted the importance of improving the profitability, and reducing the risk, of low water exchange *P. monodon* farming practices in the rice–shrimp system for achieving a farming system that is sustainable over the longer term.

Poor farming practices

While farmers have been traditional rice growers, shrimp farming is a relatively new technology, not only within the local region but more generally throughout the world. Most of the rice–shrimp farming development occurred in the late 1980s and comprised natural shrimp culture; the emergence of *P. monodon* culture within the rice–shrimp system has only occurred over the last decade. Because *P. monodon* farming generally involves more 'technology' (i.e. man-made

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ACIAR Technical Reports No. 52e
(printed version published in 2003)

inputs) and because there is farming experience elsewhere in the world, there was potential for achieving productivity gains simply by extending current best-practice technology to farmers in the region. The farm survey conducted during the project (Tran Ngoc Hai et al. this Report) documented current farming characteristics and helped to identify areas where extension of best practice could improve productivity.

The isotope analysis conducted by Burford et al. (this Report) found that a large proportion of the feed (low-quality homemade feeds) that is commonly used is likely to have very little impact on shrimp yield. In contrast, there is evidence from the isotope that returns from high-quality commercial feed inputs are high. These high quality feeds are mostly imported at comparatively high costs, which is why farmers have been using cheaper, locally made or homemade feed. Further analysis of the differences between locally made and imported feed could provide an indication of the extent to which locally made feeds can replace imported feeds in order to reduce input costs.

Quantity and quality issues in seedstock supply

The extreme shortages in *P. monodon* seedstock supply (postlarvae) throughout the Mekong Delta shrimp farming regions is discussed in Tran Ngoc Hai et al. (this Report). Most of the *P. monodon* postlarvae used to stock shrimp farms in the Mekong Delta have to be transported for several hours by road from hatcheries in central Vietnam. These postlarvae are usually in poor condition when they arrive in the Delta, and efforts to acclimatise the postlarvae to the low salinity conditions of the rice–shrimp ponds, while highly variable, are often unsuccessful. The high levels of viral infection in postlarvae (see Walker et al. 2002) further exacerbate the mortalities that occur when the shrimp experience physical stress.

The extreme shortage of postlarvae in the peak stocking period is reflected in the price premiums paid for seedstock in the early months of the dry season. Brennan et al. (1999) reported a doubling of prices in the peak period. They also noted a significant premium in the price of nursed stock compared to postlarvae that are sold directly from the trucks that import them from Nha Trang.

Financial sustainability

Farmers pay very high prices for seedstock and if losses occur, they can have serious financial problems, especially if they have borrowed money to finance their operation. For example, the cost of stocking a shrimp pond in My Xuyen in 1997[1] was 3.6 million dong, which is three times the net cash income earned from the rice crop. This implies that financial sustainability is a major concern for rice–shrimp farmers.

While good survival is critical to the success of shrimp farming, Brennan et al. (1999) point out that the relatively low input costs of the rice–shrimp system mean that survival does not have to be very high to break even. For example, survival rates only need to be 8 per cent to recover seedstock costs if no feeding is used; and 17 per cent to cover the typical costs of stocking with higher quality seed and the typical feed costs observed on farms. Many farmers (50%) in the project survey made very large profits (in excess of 10 million dong) through good survival, while many others (16%) failed to achieve the break-even survival rate and lost significant cash from shrimp farming.

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[1] Based on mean stocking rate of 1.8 postlarvae per square metre and a price of 200 dong per postlarvae (Brennan et al. 1999).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Brennan (this Report) examined the consequences of risky shrimp yield on household income and explored some of the strategies that can be employed to reduce the income risk. The role of income diversification for risk spreading was investigated. The rice and other cropping activities observed in the rice–shrimp farming system in combination with the significant level of off-farm income were shown to provide the farm with both subsistence needs and cash for the household. This diversification of farm income explains why, despite variable performance in survival, farmers practising the rice–shrimp farming system have, in general, managed to achieve financial sustainability.

Another risk-spreading strategy that was explored in Brennan (2002) is to save (or invest) in years of good production, to provide a source of cash in years of shrimp crop failure. The use of savings, either in terms of cash, gold or household assets, was an observed strategy against risk on shrimp farms in the Mekong Delta. This practice could be encouraged more widely through extension. The strengthening of microcredit schemes could provide farmers with a good return on savings, and if these funds were used to provide seasonal loans to other shrimp farmers, they would provide a means of cross-sectional 'risk pooling'. However, managers of credit services need to be fully aware of the high risks associated with lending and should encourage farmers to undertake sensible financial management, including income diversification and selecting stocking rates that they can afford.

In coming years, as shrimp technology based on pathogen-free shrimp postlarvae becomes available to farmers in the Mekong Delta, there will be choices to be made between investing in high-input 'quarantined' systems and the current extensive diversified system. The investment in pathogen-free postlarvae is likely to involve the removal of all potential sources of pathogens such as crabs and naturally recruited shrimp species, the income from which is currently widely used by rice–shrimp farmers as insurance against the risks of *P. monodon* stocking. Brennan (this Report) raises a potential policy issue that may need to be addressed with the introduction of high-quality disease-free *P. monodon*. Farmers who are able to access pathogen-free stock are likely to want to follow a '*monodon* only' stocking strategy. However, efforts by these farmers to establish a disease-free production environment may be inhibited as their poorer neighbours, for whom cultivation of mixed species systems may continue to provide important risk insurance, would provide an unwanted potential viral source to neighbouring ponds.

Emerging issues

Over the course of the project, concerns have been raised about the expansion and intensification of shrimp farming in the Mekong Delta. These concerns, which have been raised by policy makers as well as farmers at project workshops, relate in part to the on-going farm level problems that have been discussed in this chapter, such as the shrimp disease, effects of salinity on rice productivity, and problems with shrimp postlarvae quality and supply. The concerns are also raised in the context of the uncontrolled shrimp monoculture development in areas of the Mekong Delta where the local government is keen to encourage integrated rice–shrimp systems. The local governments, in the study region, are investigating the role that land zoning can play in planning and regulating the development of rice–shrimp and other farming systems in the brackish-water areas. In Le Quang Tri et al. (this Report) results are presented of an evaluation of land suitability in the Gia Rai District for the development of farming systems, particularly rice–shrimp systems. The purpose of this study was to provide assistance to local governments in developing sustainable land-use planning and infrastructure investment.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Throughout the project, local people have also emphasised the importance of disseminating the research findings from the project to farmers. In response to this need, there has been on-going work during a twelve-month project extension phase, which has detailed the best management practices arising from the research findings presented in the appendix of this Report. With assistance from DANIDA, the Mariculture Department at Can Tho University have developed an extension video and CD-ROM that details best management practices — from pond preparation and postlarvae selection through pond management during growout. These products have been widely distributed to farmers and extension officers in the region.

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Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 2

Socioeconomic characteristics of rice–shrimp farms in the study region

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Abstract

In this paper the results from the project's farm household survey are drawn upon in a discussion of the socioeconomic and production characteristics of farms in the study area. In this discussion an overview is provided on the household characteristics, the farm cropping activities, farm production practices and performance, and household income of the survey farms. The paper places particular emphasis on the shrimp farming practices and performance on the survey farms. Two types of shrimp farming practice were observed, one based on natural recruitment of shrimp seedstock with few supplementary inputs, and the other based on relatively high cash investments in *Penaeus monodon* seedstock and other inputs. The higher input systems were observed to be more prevalent in My Xuyen district compared to Gia Rai. The households practicing the higher input system made significantly more income, but faced high risk associated with shrimp mortality. The results from the survey reported here, along with more detailed information from the survey that have not been reported in this overview paper, have provided useful insights into the sustainability issues in the rice-shrimp system in the study area. This information has been used in the project either directly in developing extension material for farmers or in modifying the planned experimental work during the project.

IN THE FIRST year of the project, a cross-sectional farm household survey was undertaken with farmers from four villages in the project districts of My Xuyen and Gia Rai. The purpose of the survey was to document the main economic and social characteristics of the farm systems in the region and to identify farm management practices used in the principle farming systems. The results of this survey are reported in Brennan et al. (1999) and Brennan et al. (2000), and are drawn on here to present an overview of the socioeconomic characteristics of farm households and farming systems in the study region. The initial survey was followed up by a smaller survey of a subset of the initial farmers, and observed trends in some of the major variables are also reported in this chapter.

The four villages selected for the survey were chosen in consultation with provincial government and local commune officials. The farms within the chosen villages were randomly selected. In total, 425 farms were surveyed using a detailed questionnaire to gain an understanding of farm management practices. The survey relied upon farmers' recall of practices used in the 1997 dry and wet seasons. A smaller group of farmers who were selected from the original survey group participated in a logbook survey in the two years following the initial survey. The number of farmers interviewed for each district and village over the three years from 1997 to 1999 is summarised in Table 1.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 1. Number of farm households surveyed 1997–99.

District	Village	1997	1998*	1999*
My Xuyen		212	36	31
	Tham Don	40	7	6
	Ngoc Dong	61	11	10
	Hoa Tu 1	61	10	9
	Hoa Tu 2	50	8	6
Gia Rai		213	27	24
	Long Dien	51	3	3
	Long Dien Dong	60	13	11
	An Trach	72	11	10
	An Phuc	30	0	0
Total		*425*	*63*	*55*

*Households in 1998 and 1999 were chosen from the group in the 1997 survey

This chapter outlines socioeconomic characteristics of the survey households; gives a summary of cropping patterns of the survey farmers; describes the performance of rice and shrimp production systems, and summarises farm and household incomes.

Characteristics of farm survey households

Household size, household labour and education

The average size of households in the survey was around six people. There was no significant variation between the My Xuyen and Gia Rai districts or between the eight survey villages. In the survey households, a high proportion of family members contributed to farm labour. Two-thirds of both male and female family members in the survey aged between 12 and 60 years and 80% between the ages of 21 and 60 contributed between 5% and 100% of their time working on the farm.

Most household members (90%) in the baseline survey (within the appropriate school-age group) had a minimum of primary school education. The education levels of the household members are summarised in Table 2.

Table 2. Education levels in households surveyed.

Education level	Percentage of household[1]
No education	11
Primary	51
Intermediate	43
High school	7
Tertiary	2

[1] Variation between My Xuyen and Gia Rai was not significant and therefore only the aggregate data are shown.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Household expenditure

The average household expenditure across all categories and all households in the 1997 survey was 12.3 million dong and the average per capita expenditure was 3 million dong. There was no significant variation between the My Xuyen and Gia Rai districts.

The expenditure levels of households participating in the logbook survey are summarised in Table 3. In 1998 the mean expenditure of 23.3 million dong was significantly higher than the mean expenditure of 13 million dong in 1997 and 10.2 million dong in 1999.

Table 3. Household expenditure ('000 dong per household)

Variable	1997[1]		1998		1999	
	Average	Per cent	Average	Per cent	Average	Per cent
House	1 747	*13*	4 434	*21*	2 125	*21*
Food	5 485	*42*	6 281	*29*	2 301	*23*
Clothes	905	*7*	979	*5*	647	*6*
Education	1 325	*10*	1 440	*7*	402	*4*
Health	669	*5*	2 063	*10*	339	*3*
Social	1 682	*13*	2 105	*10*	1 137	*11*
Assets	617	*5*	3 561	*17*	2 967	*29*
Other	618	*5*	705	*3*	269	*3*
Total	13 048[b]		21 567[a]		10 187[b]	

[1] 1997 data was restricted to logbook subset. There was no significant difference in means between the full data set and the logbook subset for each expenditure item.
[a, b] significant difference at 10% level, a>b.

Household cropping activities

The average farm size in each of the survey districts was 2.3 ha in My Xuyen and 2.6 ha in Gia Rai (Gia Rai significantly higher at the 10% level). On most of the farms surveyed, the land area was allocated between several cropping activities. The majority of farmers who were surveyed practised some kind of shrimp culture and in My Xuyen district, most of the farms also grew rice. Rice was grown in both rice monoculture plots and in the rice–shrimp system. Shrimp were also grown in monoculture and in integrated rice–shrimp systems. It was common for the area allocated to shrimp farming to also be used for raising crabs, fish or other crustaceans. Some farmers also had plots of land that they allocated to upland agricultural cropping activities. In Table 4, the number of farmers practising the principal cropping activities is summarised.

Table 4. Cropping activities on survey farms (1997).

	My Xuyen	Gia Rai
Total number of farms	212	212
Per cent of farms that grew:		
Rice	98	61
Shrimp	97	97
Other crops	92	95
Per cent of shrimp farms practising:		
Monodon	19	2
Natural	17	46
Both monodon and natural	63	51
Per cent of rice farms practising:		
Rice monoculture	5	29
Rice–shrimp	58	45
Both systems	37	25

Rice production in the rice–shrimp system

Many of the rice–shrimp farmers in the 1997 baseline survey grew rice both in monoculture plots and in their rice–shrimp polders. Most of the farmers in My Xuyen District grew rice, but in Gia Rai there was a high percentage of farmers who did not grow rice in the 1997 season. In one of the survey villages in Gia Rai (An Phuc) there was no rice planted. The rice varieties grown by survey farmers included traditional and modern varieties.

A survey in 1997 determined rice yields in rice–shrimp and rice monoculture plots. The average yield in rice monoculture plots was generally higher compared to rice grown in the rice–shrimp system. The mean difference was statistically significant in all survey villages in Gia Rai and for Hoa Tu 2 village in My Xuyen District.

While rice cropping was an important subsistence activity for farmers in the survey, there is some indication that rice growing has been declining in the areas surveyed. The number of farmers in the logbook survey who grew rice declined over the three years of the survey. This is thought to be a result of the relatively high benefits possible from extending shrimp production but also because of poor conditions for rice in the 1998–99 season because of high salinity from an abnormally long dry season.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Shrimp farming practices and trends

Shrimp stocking practices

The shrimp culture practices of farmers in the 1997 baseline survey are summarised in Table 5. The majority (90%) of rice–shrimp farmers interviewed in the 1997 survey harvested natural shrimp. In the table and in the analysis that follows, farms are categorised into those that grow *P. monodon* and those that do not. The stocking of *P. monodon* requires a significant cash investment and results in significantly different income per hectare. However, those farmers practising monodon also tend to harvest some natural shrimp — some recruitment of natural shrimp takes place as part of the water exchange process that occurs during the *P. monodon* cycle. Results from the survey indicate that there is a wide range in the water exchange practices used during the *P. monodon* stocking period, and as a result, there is a wide range in the yield of natural shrimp in *P. monodon* systems, as shown in Table 5. In general, the practice of natural shrimp recruitment by *P. monodon* farmers was found to be more common in Gia Rai than My Xuyen.

Table 5. Shrimp systems among survey farmers

Farm group	Number of farms	
	My Xuyen	Gia Rai
Farms with monodon		
Monodon only	35	4
Natural shrimp in wet season only	34	2
Natural shrimp in dry season only	16	23
Natural shrimp in both wet and dry seasons	84	90
Total Farmers	169	119
Farms without monodon		
Natural shrimp in wet season only	1	0
Natural shrimp in dry season only	8	17
Natural shrimp in both wet and dry seasons	28	71
Total Farmers	37	88

The timing of stocking and harvesting of *P. monodon* varied widely amongst the survey farms. In My Xuyen there is a peak stocking period for *P. monodon*, which occurs in the dry season from December to March; it is particularly high in January. In contrast, in Gia Rai there was very little stocking of *P. monodon* during the peak stocking period. Our subsequent discussions with local farmers and officials in the district revealed two economic explanations for this. First, farmers in Gia Rai found that they couldn't afford the price premiums that are present in the peak stocking months. Second, they were unable to access formal credit during the dry season (because the land was not zoned for 'rice–shrimp' culture) and this meant that they could only borrow money during the wet season, supposedly for rice cropping, in order to finance the purchase of monodon postlarvae.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

The average stocking rates of *P. monodon* in 1997 across all crops for each survey village are summarised in Table 6. There was a large variation in stocking rates observed across districts and across farms within each district. The stocking rates in My Xuyen were higher compared to those in Gia Rai. For example, in 1997 only 30% of the survey farmers stocked at less than 1 PL/m^{-2}, whereas in Gia Rai 75% of farmers had a stocking rate of less than one PL/m^2.

Table 6. Average stocking rates in 1997 (PL/m^2).

District	Village	N	Mean	Min	Max
My Xuyen	Tham Dong	14	1.22 *(0.28)* a	0.06	3.70
	Ngoc Dong	55	1.72 *(0.22)* a	0.30	11.43
	Hoa Tu 1	55	1.46 *(0.12)* a	0.28	4.71
	Hoa Tu 2	45	2.18 *(0.20)* b	0.18	7.69
District level		169	1.72 *(0.10)* *		
Gia Rai	Long Dien Dong	33	0.84 *(0.10)*	0.14	2.21
	Long Dien	9	0.76 *(0.24)*	0.07	2.50
	An Trach	52	0.72 *(0.05)*	0.24	1.70
	An Phuc	14	1.23 *(0.23)*	0.31	2.96
District level		108	0.83 *(0.05)* *		

b significantly higher than a (at 5%).
*MX significantly higher than GR (at 0.1% level).

The stocking rates for the logbook farmers from 1997 to 1999 are shown in Table 7. The results indicate a general increase in the stocking rates over the three years. The results in Table 7 indicate that the increase in the stocking rates from around 1.4 PL m^{-2} in 1997 to 1.9 PL m^{-2} in 1999 (significantly different at 5% level) occurred primarily in My Xuyen where the average stocking rate increased from around 1.7 PL m^{-2} in 1997 to 2.6 PL m^{-2} in 1999 (significant at the 1% level). In Gia Rai there was no significant increase in the average stocking rate over the survey period.

These data support broader anecdotal evidence of increased *P. monodon* stocking intensity over the course of the project. For example, during annual project workshops local farmers and representatives from district agricultural and fisheries departments were called on to lead the discussion on developments in the region. One of the most significant concerns raised during these discussions, particularly by My Xuyen representatives, was the progressive increase in stocking density — they reported that stocking rates of 5–10 post larvae per square metre were becoming the norm.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 7. Average stocking rates for logbook survey farms 1997–1999 (PL m^{-2}).

Year		N	Mean	Min	Max
1997[1]	My Xuyen	33	1.66 *(0.20)* a	0.06	5.38
	Gia Rai	17	0.90 *(0.15)*	0.20	2.21
	Year average		1.40 *(0.15)* *		
1998	My Xuyen	27	1.49 *(0.17)* a	0.24	4.33
	Gia Rai	30	1.45 *(0.38)*	0.24	11.44
	Year average		1.47 *(0.21)* n.s		
1999	My Xuyen	28	2.58 *(0.25)* b	0.40	6.45
	Gia Rai	20	1.00 *(0.20)*	0.22	3.83
	Year average		1.92 *(0.20)* *		

[1]Includes only data for the logbook sub-sample of farmers.
Across years: * significantly different at 5% level; n.s not significantly different from other years.
Between districts across years: a,b significantly different at 1% level; no significant difference for GR at 1% level.

Shrimp production costs

The cash inputs in the systems primarily based on natural recruitment of shrimp were very low. In contrast, *P. monodon* farmers tend to spend large amounts of cash on stocking, feed and other inputs. The cash outlay in the *P. monodon* systems is very high in proportion to the average income earned from other farm and household activities, which poses significant risk to households investing in *P. monodon* production. The cash input costs are summarised in Table 8.

Table 8. Components of shrimp production costs (dong/ha).

	Monodon	Natural
Stock	2 719.2 *(169.2)* *	0
Feed	1 970.4 *(243.6)* *	9.6 *(4.8)*
Polder	435.6 *(43.2)*	841.2 *(109.2)* *
Other	342 *(28.8)* *	144 *(33.6)*
Total	5 467.2 *(370.8)* *	994.8 *(117.6)*

* Significantly higher at 1% level.

The main cost of polder preparation is the labour cost of removing sediment built up from the previous season's shrimp crop. These costs were significantly higher for the shrimp farms relying on natural recruitment as the higher water exchange needed for recruitment of shrimp from the river canal results in more significant sedimentation.

The cost of shrimp seed varied depending on the time of stocking. For example, in the peak stocking period (December to March) of the 1997 season, the average price paid for postlarvae purchased from local nurseries was around 20 600 dong per hundred postlarvae, compared to around 10 500 dong per hundred postlarvae in the off-peak period (significantly different at 1%

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

level). A significant price premium also applies to nursed stock versus seed stock purchased directly from a truck. In the 1997 season, the premium paid for nursed stock was around 7 800 dong per hundred postlarvae in the peak season and 5 200 dong per hundred postlarvae in the off peak season in My Xuyen.

Feed and other input use

Feeding in natural shrimp systems is very low or zero. In *P. monodon* systems, feeding practices were found generally to vary with the level of investment in *P. monodon* seedstock. For example, many farmers stocking *P. monodon* at intensities of less than one postlarvae per square metre did not practise supplementary feeding. The use of supplementary feeds on survey farms in 1997 is summarised in Table 9.

Table 9. Number of farms using supplementary feeds.

Farming System		My Xuyen	%	Gia Rai	%
Monodon	Do feed	166	98	29	26
	Do not feed	3	2	81	74
Natural shrimp only	Do feed	7	19	2	2
	Do not feed	30	81	95	98

On the farms using feed, a combination of protein-based feeds — either fishmeal or manufactured feed pellets — and rice-based feeds was used. Farms stocking *P. monodon* at higher stocking rates (>2 PL/m^{-2}) were more likely to use manufactured feed pellets. The price for manufactured feed varied, reflecting different levels of feed quality. The most expensive feed was imported (usually Charoen Pokphand [CP Group] feed) from Thailand at an average of 16 000 dong per kilo. The price of a locally manufactured feed was around 8 000–10 000 dong per kilo. Other farmers were using pellets with an average price of around 5 000 dong per kilo and these were found to be poultry or fish feed being marketed as shrimp feed.

In terms of total biomass of feedstuff added to the pond, rice products (particularly broken rice, rice bran and rice porridge) were the most commonly used feed, comprising 40% of the total weight of feed. Regression analysis of shrimp yield as a function of feed inputs failed to find any significant relationship between rice inputs and shrimp yield. The significant factors in the regression equation, reported by Brennan et al. (2000) are demonstrated in Equation 1.

Equation 1

$$\text{Yield} = 64.2\,\text{StkRate}^{***} - 6.2\,(\text{StkRate}^2)^{**} + 0.4867\,\text{FeedA}^{***} + 0.3091\,\text{FeedB}^{***} + 0.1464\,\text{FeedC}^{***} + 0.0971\,\text{FishMeal}^{***} + 0.22^{*}\text{Fertiliser}^{*} - 27^{*}\text{GR}^{**}$$

where:

Yield = monodon shrimp yield in kg/ha

StkRate = stocking density, number of postlarvae per square metre

FeedA = quantity of grade A manufactured feed pellets (imported) kg/ha

FeedB = quantity of grade B manufactured feed pellets (locally produced) kg/ha

FeedC = quantity of grade C manufactured feed pellets (general purpose) kg/ha

FishMeal = quantity of fishmeal kg/ha

Fertiliser = quantity of fertiliser kg nitrogen/ha

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

GR = dummy variable representing shrimp ponds in Gia Rai district

Significance: *** 0.1% level, ** 5% level, * 10% level

Equation 2

R^2 = 0.79, 159 observations

The lack of significance of rice inputs is supported by isotope analysis conducted on shrimp selected from the project's experimental ponds, reported in Burford et al. (this Report), which found that rice feeds provide little or no nutritional value to shrimp. These results imply that farmers are wasting resources by adding rice-based feeds to the pond, while also jeopardising water quality by adding useless organic matter to the pond.

Other commonly used inputs to production include derris, a natural piscicide which is used on the majority of farms in all districts. Lime was widely used in My Xuyen (75% of farmers), but in Gia Rai it was less common. Direct application of fertiliser in the shrimp pond is not common on the farms, although fertiliser application during the rice crop may provide an indirect source of fertiliser to the shrimp pond.

Shrimp yields

The average shrimp yields in 1997 are summarised in Table 10. The natural shrimp yields are higher in Gia Rai compared to My Xuyen, and there is little difference in natural shrimp yields between farming systems. In contrast, in My Xuyen the natural shrimp yields obtained on *P. monodon*-based farms are lower than the yields on farms without *P. monodon*. This is likely to be a result of the lower water exchange strategy adopted by rice–shrimp farmers in My Xuyen raising *P. monodon* shrimp.

Table 10. Average shrimp yields in 1997 across survey farms.

	My Xuyen	Gia Rai
	kilograms per hectare per year	
Monodon yields (single harvest)	138.7 *(12)*	13.92 *(2)*
Natural shrimp yields		
Monodon based	99.7 *(10)*	239.4 *(16)*
Natural only	181.2 *(26)*	245.2 *(24)*
Total shrimp yield		
Monodon based	251.3 *(17)*	260.5 *(24)*
Natural only	181.3 *(26)*	245.2 *(24)*

The average yield for *P. monodon* observed in the study area was very poor relative to yields reported for extensive farming systems in Bangladesh (212 t/ha) and the Philippines (260 t/ha), where similar stocking rates are used (Shang et al. 1998). The low average yields in the study area reflect the very low mean survival rates of *P. monodon* across farms surveyed. The average survival rates for farmers in the 1997 survey are summarised in Table 11.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 11. Summary of data on survival rates in 1997 for My Xuyen and Gia Rai survey farms.

District	N	Mean (%)		N (0 survival)	N (>50%)
My Xuyen	169	29.24	*(1.40)*	8	23
Gia Rai	108	8.62	*(1.04)*	23	0

There was substantial variation in the survival rates on survey farms. Some farmers in the survey experienced total crop loss (100% mortality) due to disease outbreaks. However, other farmers were able to achieve reasonably high shrimp survival rates of 50% or more. In My Xuyen, farmers experienced significantly higher shrimp survival compared to Gia Rai. The cumulative frequency of survival (Fig. 1) illustrates this difference between the two districts and also shows the variability in survival rates among farms within each district.

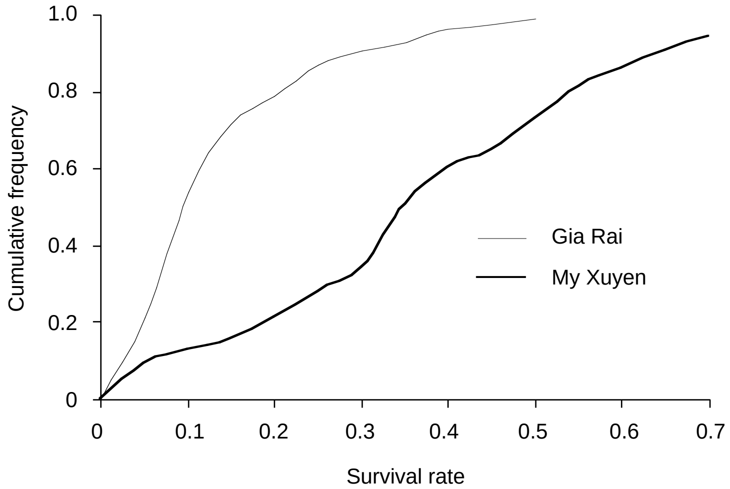

Figure 1. Frequency distribution of *P. monodon* survival in 1997 survey.

The social and financial implications of the production instability arising from the poor *P. monodon* survival rates raises important sustainability concerns for the rice–shrimp system in the Mekong Delta. The implications for farm financial management arising from poor survival are addressed in Brennan (this Report).

Summary of farm and household income

Apart from rice and shrimp production, other sources of farm income (in the survey sample) included vegetable cash crops, poultry and livestock, and other types of aquaculture crops including fish, crabs and freshwater prawn culture. Shrimp was the most important source of income on the farms that raised shrimp. In Table 12, the total income from all farming activities is compared between *P. monodon*-based farms, natural-shrimp-based farms and farms with no shrimp. As shown in the table, farm households growing shrimp earned more per hectare than

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

the rice-only farms in the sample. Monodon farming systems yielded significantly higher income per hectare compared to natural-based systems in My Xuyen. Monodon attracts a much higher price than natural shrimp and, on average, the revenues earned by *P. monodon* farmers in My Xuyen more than recouped the cash investment made. In Gia Rai, the average income per hectare was higher for *P. monodon*-based systems, but the difference in means was not significant at the 10% confidence interval. The relatively poorer performance of *P. monodon* farming in Gia Rai is due to the low survival rates, as discussed earlier.

Many farm households were engaged in off-farm employment, which included labouring, retailing and tailoring. These sources of income contributed about 20% of total household income. The total income earned per household is also shown in Table 12.

Table 12. Comparison of farm and household income for different farming systems.

Farming system	N	Farm size (ha)		Farm cash income (dong per ha)		Household income (dong per household)	
All Farms							
Monodon	278	2.50	(1.32)	3 806.52	(321.96)	11 646.72	(948.36)
Natural	138	2.39	(1.38)	2 225.04	(272.16)	6 343.32	(627.24)
No Shrimp	8	1.27	(0.95)	537.72	(678.96)	1 488.72	(1 472.04)
By District							
My Xuyen							
Monodon	169	2.38	(1.23)	4 172.4	(452.16)	12 250.08	(1 339.2)
Natural	39	2.04	(1.23)	1 613.64	(357.36)	4 907.76	(736.44)
No Shrimp	3	1.12	(0.79)	912.6	(530.64)	764.4	(269.16)
Gia Rai							
Monodon	109	2.69	(1.43)	3 239.16	(424.44)	10 711.44	(1 242.72)
Natural	99	2.53	(1.42)	2 465.88	(50.4)	6 908.88	(819.96)
No Shrimp	5	1.35	(1.11)	312.72	(1 082.76)	1 923.24	(2 433.12)

Summary

The survey conducted during the project revealed a wide variety of farming practices on the farms in the region. Nearly all farmers grew shrimp, and the most significant difference between farmers, in terms of potential income, was whether or not they practised *P. monodon* stocking. The survey revealed a number of useful insights into farming practices that were either used directly to provide input into extension material or used in modifying planned experimental work during the project. For example:

- The information on the performance of shrimp feed inputs was followed up by experimental work on shrimp nutrition, which included isotope analysis of sources of shrimp nutrition in rice–shrimp ponds (Burford et al. this Report), and experimental trials conducted by the Can Tho University Mariculture Department on various homemade feed formulations (Nguyen Thanh Phuong, 1999, Personal communication).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

- The very high water exchange rates being practised on some farms during monodon cycles was considered to be poor practice by the scientific team, and experiments were subsequently designed to demonstrate the effect of water exchange on pond water quality, as reported in Tran Thi Tuyet Hoa et al. (this Report).
- The information on the very poor survival rates of *P. monodon* in the study area, and particularly Gia Rai, helped to highlight the extent of the seedstock supply and health-screening problems. Subsequently, extra emphasis was placed on the study of health and survival issues and seedstock supply problems during project workshops. Bioeconomic analysis of the implications of poor survival on farm income risk was also undertaken (Brennan this Report).

Some of the results that were of direct use to the project included detailed information about shrimp-farming practices that are not reported in this overview. For example, poor hygiene was observed on a number of farms in the study (where farmers were restocking after shrimp disease outbreaks without disinfecting the pond), and this indicated an urgency for extension material on simple pond hygiene practices. Farmers' lack of knowledge about how to identify good quality postlarvae was identified and subsequently information on simple visual screening methods was provided in extension leaflets.

The survey also provided the necessary background for much of the bioeconomic analysis that was conducted during the project. For example, Clayton (this Report) explores the underlying economic incentives that have driven the land degradation (land loss through sedimentation) that was observed in Gia Rai.

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Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 3

The shrimp pond environment: factors affecting shrimp production

Part A: Growth and survival of *Penaeus monodon* in relation to the physical conditions in rice–shrimp ponds in the Mekong Delta

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Abstract

The growth and survival of *Penaeus monodon* and the variations in temperature, salinity, dissolved oxygen, turbidity and pH were monitored in shallow rice–shrimp ponds in two study areas in the Mekong Delta, Vietnam. In 1998, three farms (1 ha, 1 ha and 1.3 ha) were monitored in My Xuyen from March to June. In 1999, three farms (0.4 ha, 0.5 ha and 0.5 ha) were monitored in Gia Rai from February to May. At all locations the ponds had a shallow central platform area (≈ 80% of the total pond area, 20 cm deep) and a trench (1 m deep) around the perimeter of the platform. The platform area was used for wet season rice crops prior to the dry season shrimp crops that we monitored. The ponds were stocked with hatchery-reared *P. monodon* postlarvae at low densities, 1.65 m^{-2} at My Xuyen and 3 m^{-2} at Gia Rai. There was pronounced diurnal variation in pond temperatures, dissolved oxygen and pH. In general, the conditions on the platform were more extreme than in the adjacent ditch. Assuming the shrimp were able to avoid the platform extremes, the physical conditions in the ditch of the My Xuyen ponds were within acceptable tolerance limits for *P. monodon*. This was reflected in the growth rates (25.6 g in 110 days), survival (83–94%) and pond yields (344–436 kg/ha). At the Gia Rai farms during 1999, the pond temperatures, dissolved oxygen and pH values were similar to those recorded at My Xuyen the previous year. However, a period of heavy rain at the end of April resulted in a very rapid drop in pond salinity, from 10 ppt to 1 ppt over three days. Prior to the onset of the rains, the growth rate and survival of *P. monodon* were comparable to My Xuyen. However, the onset of the heavy rains coincided with mass mortalities in all ponds. Initial observations indicated that the *P. monodon* were probably infected with WSSV (white spotsyndrome virus). This was subsequently confirmed by PCR analysis. The results of this study emphasise the need to learn more about the prevalence of shrimp viral disease in Vietnam and the sources of infection of postlarvae and farm stocks.

IN THE RICE–SHRIMP cultivation system, the pond water depth (particularly in the central platform area) is, of necessity, much shallower than in conventional shrimp monoculture, leading

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

to more extreme physical conditions. It is possible that these extremes might, at times, compromise shrimp survival. It was therefore of critical interest to farmers and environmental managers to determine the key factors responsible for shrimp mortalities in this system. So far, most of the quantitative information on the physical factors that affect the growth and survival of farmed shrimp have come from studies of intensive shrimp-farming systems. For example, studies of intensive systems have shown that survival and growth of *Penaeus monodon* are affected by variations in key physical factors including pond temperature (Jackson and Wang 1998), salinity and dissolved oxygen.

However, the relationship between variations in these parameters on the growth and survival of *P. monodon* in the rice–shrimp farming systems has not been determined. Accordingly, the objective of this study was to determine quantitatively the physical conditions in the pond during the shrimp production system and assess the influence of variations in these conditions on the growth and survival of *P. monodon*.

Materials and methods

The study area was in My Xuyen District (Soc Trang Province) in 1998 and Gia Rai District (Bac Lieu Province) in 1999 (see Figure 3, Chapter 1 this Report). The study sites were three rice–shrimp farms (1 ha, 1 ha and 1.3 ha) in My Xuyen which were monitored from March to June 1998, and three rice–shrimp farms in Gia Rai (0.4 ha, 0.5 ha and 0.5 ha) which were monitored from February to May 1999. The farm ponds all had a central platform area (80% of the total pond area, approximately 20 cm deep) where a wet season rice crop was grown prior to the dry season shrimp crop. The platform was surrounded by a ditch approximately 1 m deep. Prior to stocking, ponds were prepared by removal of sedimented material in the ditches, drying the platform, liming the entire pond and killing predators with rotenone.

Pond stocking management and monitoring

The ponds were stocked with *P. monodon* postlarvae (mean total length: 18 mm) that had been transported by road from a hatchery in Nha Trang. The postlarvae were only selected for stocking if they survived a stress test of ten minutes immersion in 150 ppm formalin. Postlarvae were acclimated to ambient ditch conditions for about one hour before stocking. The mean stocking density was 1.65 m^{-2} at the My Xuyen farms and 3 m^{-2} at the Gia Rai farms. The My Xuyen farms were stocked in February 1998. The Gia Rai farms were stocked in March 1999 — this was the second crop for that year.

At the My Xuyen farms the shrimp were fed a commercial pelleted feed for the first month. The shrimp were then fed a home-made food including: rice (30%), rice bran (15%), fish meal (50%), premix (2.5%), vitamin C (2.5%) and trash fish. At the Gia Rai farm, the shrimp were fed with commercial pelleted feeds.

Sampling

During the experimental period, temperature, salinity, turbidity, dissolved oxygen and pH were monitored daily at three sites on both the platform and the ditch in the early morning and late afternoon using a datalogger (YEOKAL). Twice per month, on every spring tide, the same parameters were monitored in the supply canal.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Samples of shrimp were taken every two weeks using a cast net. The minimum number of shrimp collected was 100 for small shrimp (<2 g) or 50 for larger shrimp (>2 g). The mean weight was calculated as the total weight divided by the number of individuals.

Results

Diurnal and spatial variability

There was pronounced diurnal variation in pond temperatures, dissolved oxygen (DO) and pH. For example, at the ponds in My Xuyen province the mean daily difference in temperature was 5.5°C; in pH it was 0.75; and in DO it was 5.3 mg.l^{-1} (Fig. 1). Occasionally, the diurnal difference was much greater than these averages; for example, early in the season the daily pH variation was 1 unit or more for several days. Afternoon surface temperature reached 37°C on one occasion and was frequently above 34°C (Fig. 1).

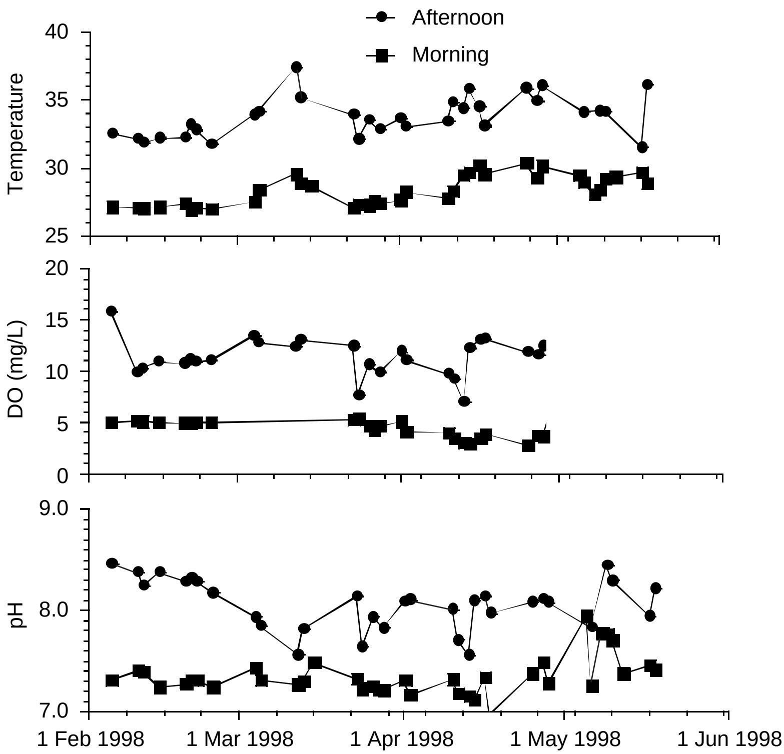

Figure 1. Afternoon and morning temperatures, dissolved oxygen (DO) and pH at ditch surface at a rice–shrimp farm in My Xuyen.

In Gia Rai during 1999, problems with the datalogger meant that the data were not as comprehensive as the My Xuyen data. Dissolved oxygen was unreliable throughout, and pH was inaccurate after late April, being measured only by pH indicator paper. However, the data suggest that conditions were similar to the My Xuyen farms studied in the previous year. The average

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

diurnal temperature range was 5.2°C and the average diurnal pH range during the period before late April was 0.59 pH units (Fig. 2).

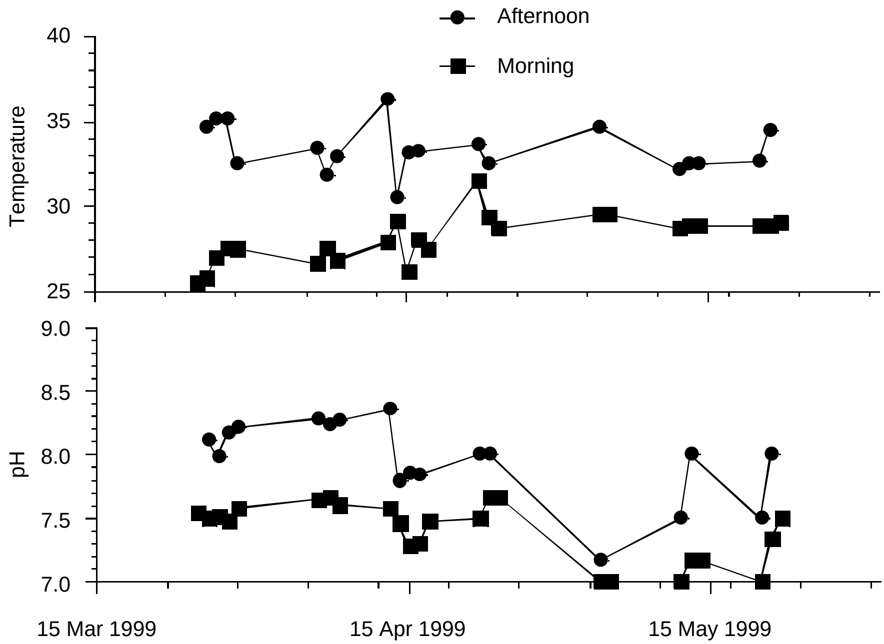

Figure 2. Afternoon and morning temperatures and pH at ditch surface, at a rice–shrimp farm in Gia Rai.

Conditions in the deeper water of the ditch were not as extreme as those on the platform. Afternoon temperatures at the bottom of the ditch were, on average, about 1.6°C cooler than on the platform (Fig. 3).

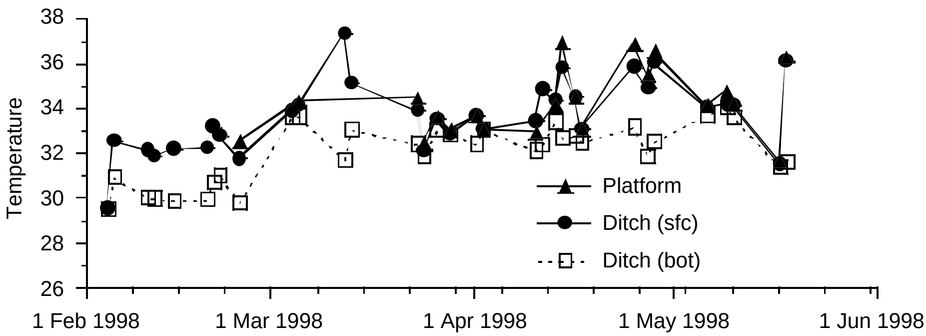

Figure 3. Afternoon temperatures on the platform and ditch (surface and bottom) at a rice–shrimp farm in My Xuyen.

Salinity

The pond salinity was quite different in the two years studied. In My Xuyen during 1998, the salinity gradually increased from about 6 ppt at the beginning of February (when the ponds were

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

first stocked) to about 16 ppt at harvest time in mid-May. There was some rainfall from mid-April onward, but this only marginally affected the pond salinity (Fig. 4A).

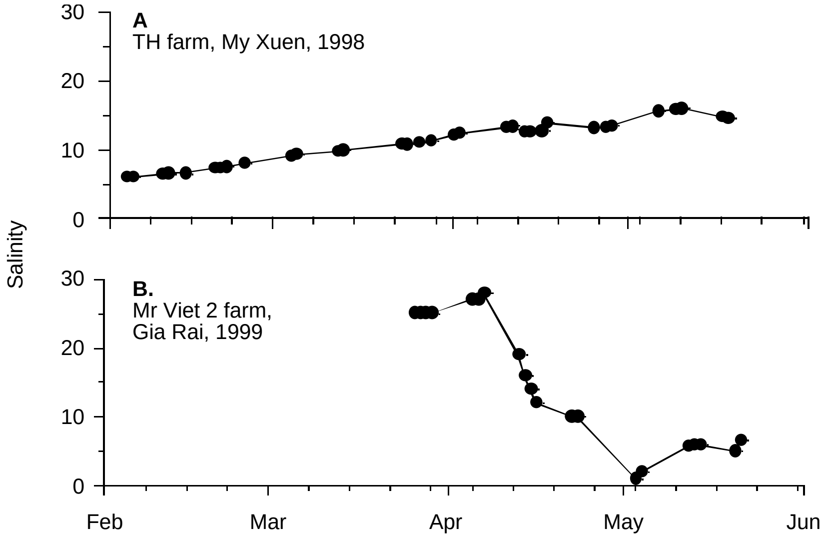

Figure 4. Salinity (ditch surface samples): A in My Xuyen, 1998; and B in Gia Rai, 1999.

In contrast, by the time the shrimp were stocked in Gia Rai the next year (late March), the salinity had already reached 25 ppt and by the second week in April it was at 30 ppt. This was followed by a period of heavy rain resulting in a rapid decline in salinity, which reached close to zero at the beginning of May. The final drop, from 10 ppt to about 1 ppt, occurred over only a 3 day period (Fig. 4B).

Growth and survival

Production at My Xuyen in 1998 ranged from 344 to 436 kg, with a mean harvest of 392 kg ha^{-1}. Survival at My Xuyen in 1998 ranged from 83 to 94% with a mean value of 89% (Table 1).

Table 1. Shrimp production and survival rate after 110 days at My Xuyen in 1998.

Pond	1	2	3
Production (kg)	344	436	396
Survival rate (%)	83.0	87.2	93.7

Over the 110 day crop, growth at each of the three My Xuyen farms was similar: the final average weight of shrimp was 25.64 g (Fig. 5). Over the crop, the average growth rate was 0.23 g/d.

In Gia Rai during 1999, initial growth was also good: the average growth rate over the first 41 days was 0.29 g/d, better than My Xuyen the previous year (Fig. 6). However, when the

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

salinity began to drop quickly during April, symptoms of WSSV (white spot syndrome virus) appeared and shrimp mortality was very high.

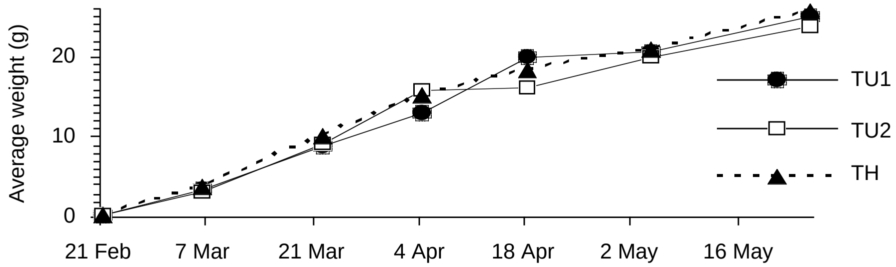

Figure 5. Shrimp growth after 110 days in My Xuyen District.

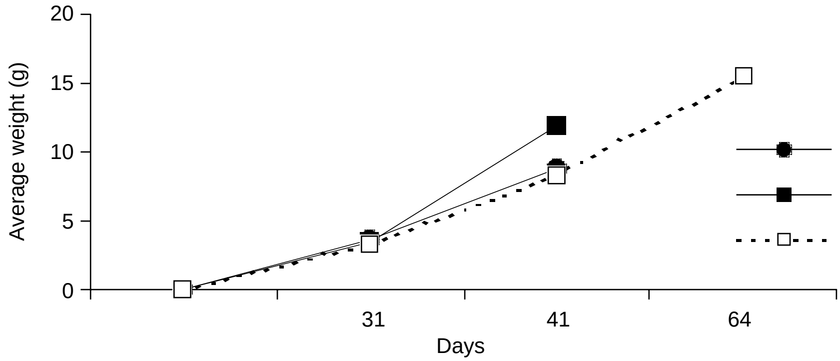

Figure 6. Shrimp growth after 64 days in Gia Rai District in 1999.

Discussion

The daytime pond water temperatures in the shallow platform area of the rice–shrimp ponds regularly reached more than 33°C. This is a higher temperature than the generally-accepted maximum for good growth (Lester and Pante 1992; Chen 1984) and almost 10°C above preferred temperature (Chen and Chen 1999). However, the effects of high temperatures on the growth and survival of *P. monodon*, or the capacity of this species to acclimatise to high temperatures, are not well understood. Within the ditch area of the rice–shrimp ponds the temperature and other physical parameters were more moderate. Although we did not monitor their distribution, it is possible that the shrimp avoided the daytime extremes by moving to the deeper areas of the pond. In general, during the dry season, the characteristics of the pond water in the deeper sections of rice–shrimp farms at both My Xuyen and Gia Rai were within the water quality conditions considered suitable for *P. monodon* growth. The growth and survival of *P. monodon* in the ponds at My Xuyen are indicative of what can be achieved in the absence of disease and are comparable to those obtained for *P. monodon* grown in intensive shrimp culture ponds in nearby farms.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

During the second year in Gia Rai, two factors combined to cause a drastic fall in production. First, heavy rains caused pond salinity to drop rapidly and severely: in less than a month, the salinity dropped from 30 ppt to 1 ppt. The severity and suddenness of the drop would have stressed the shrimp, and under any circumstances probably caused loss of production. Second, this effect was made worse by the presence of WSSV, which was probably in the postlarvae at the time of stocking. It seems likely that the stress of sudden low salinity provided the trigger necessary to cause WSSV disease and widespread mortality.

The results of this study suggest that stocking ponds early in the dry season, as was done in My Xuyen during 1998, reduces the risk of crop losses due to the onset of the wet season and rapid decreases in pond salinity. In the absence of WSSV, a single summer crop grown to a large size would bring greater returns than the two small crop strategy adopted by Gia Rai farmers. However, because of the presence of WSSV, particularly if the postlarvae are infected to start with, the farmers may have little choice but to try to spread their risks by harvesting as soon as they can. Ultimately, the solution to this dilemma is to eliminate WSSV from the postlarvae. This can only be done with certainty if the industry progresses from the current high level of reliance on wild broodstock, particularly those that have not been screened for viral diseases, to domesticated Specific Pathogen Free (SPF) stocks. In this respect we strongly endorse the recommendations of Johnston et al. (2000) that a high priority be given to improving the quality of hatchery-reared postlarvae. Their study examined the mixed shrimp and mangrove forestry farms in southern Vietnam, but it is increasingly evident that the lack of sufficient supplies of good quality postlarvae is a threat to the sustainability of all forms of shrimp farming in the region.

The results of this study of *P. monodon* in rice–shrimp ponds emphasise the need to learn more about the prevalence of shrimp viral disease in Vietnam and the sources of infection of postlarvae and farm stocks. This needs to be done in parallel with improving the quantity and quality of locally available seedstock for stocking shrimp farms in the Mekong Delta. There is now strong evidence that the major pathogens of farmed shrimp in Asia (yellow head virus and white spot syndrome virus) are vertically transmitted and enter the production system via infected broodstock or naturally recruited postlarvae (Lo et al. 1997; Walker et al. 2001). In the case of white spot syndrome virus, PCR screening in hatcheries has proven to be effective in reducing the risk of disease on farms (Withyachumnarnkul 1999; Hsu et al. 1999) and again points to the use of domesticated SPF stock as a route to future sustainability of the industry.

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Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

Part B: Preliminary observations of the effects of water exchange on water quality, sedimentation rates and the growth and yields of *Penaeus monodon*in the rice–shrimp culture system

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TRADITIONALLY, RICE–SHRIMP farmers have relied on capturing and retaining naturally occurring shrimp postlarvae or juveniles that enter the ponds via water exchange during high tides. The naturally occurring species include *Penaeus merguiensis*, *P. indicus* and *Metapenaeus ensis*. More recently, the preferred option for most farmers has been to stock their ponds with hatchery-reared *P. monodon*. Many of the *P. monodon* farmers, particularly those in regions where shrimp farming has been established for some time, continue the practice of tidal water exchange in order to capture naturally occurring postlarvae. Although this practice can increase farm income, it can also have significant negative consequences due to increased sedimentation and increased risks of exposure to viral diseases. The negative consequences of increased sedimentation due to frequent water exchange are described in Chapter 11 this Report. The level of risk of the exposure of *P. monodon* to viral diseases carried by *P. merguiensis*, *P. indicus* and *M. ensis* have yet to be determined.

One method of reducing the amount of sedimentation and possibly lowering the risks of exposure to viral disease would be to reduce water exchange. To assess the effects of reduced water exchange we conducted a preliminary trial in collaboration with rice–shrimp farmers from the Gia Rai District. The objective of the study was to compare pond water quality and the growth, survival and harvest of *P. monodon* from adjacent ponds with low and high water exchange frequency.

Materials and methods

Experimental design

In the initial experimental design there were five participating farms in the Gia Rai District, each with rice–shrimp ponds of approximately 1 ha. The farms were monitored from December 1999 to March 2000. Three treatments were established: low water exchange (two farms), medium water exchange (one farm) and high water exchange (two farms). In the low exchange ponds, water was only introduced if necessary to maintain water levels. In the medium exchange pond, water was exchanged on one day each month. In the high exchange ponds, there was daily water exchange throughout the spring tides. However, the initial experimental design was compromised by the loss of replicates and problems with disease. One of the low-exchange treatments was abandoned because the farmer reverted to frequent water exchanges, and one of the high exchange farms experienced high shrimp mortalities. The loss of these treatments means that this study was restricted to preliminary observations of the effects of low, medium and high water exchange in single ponds. We have included these observations in this report on the basis that they may assist in the design of future, replicated studies on the effects of variations in water exchange.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Methods

The low exchange pond (1.2 ha) and high exchange pond (1.5 ha) were adjacent to each other on the same farm site (Farm A, Table 1). The medium exchange pond, Farm B, was at a second farm approximately 1 km from Farm A.

Prior to filling, the pond platform had been dried, limed and fertilised as recommended in our best management practices (Appendix, this Report). The ponds were filled from the adjacent canal via a sluice. All the ponds were stocked with *P. monodon* postlarvae (mean total length 18 mm) from the same hatchery. The postlarvae were subjected to a stress test (150 ppm formalin) and acclimated to ambient pond conditions for about one hour before stocking. Shrimp in the low-exchange pond were fed twice a day with a commercial feed (KP-90) shrimp in the medium and high exchange ponds were not fed.

Table 1. Pond size and stocking rate in the low, medium and high water exchange ponds.

Farm	Farm A	Farm B	Farm A
Pond size (ha)	1.2	1.4	1.5
Stocking density (PL/m^2)	3.0	3.0	1.0
Water exchange	Low	Medium	High

During the experimental period, water quality parameters (temperature, salinity, turbidity, dissolved oxygen and pH) were monitored twice-daily (dawn and afternoon) using a datalogger. Three sites on both the platform and the ditch were monitored. Both surface and bottom measurements were taken in the ditch.

Samples of water and sediment nutrients (TN, TP in water and sediment, TSS, chlorophyll *a*, NOx, total ammonia and FRP) were taken every month and analysed using standard methods (APHA 1995). Samples of plankton, shrimp (*P. monodon* and natural shrimp) were collected from the low water exchange farm with a plankton trawl (200 µm mesh) and beam trawl (1 mm mesh). These samples, together with the feed pellets, were analysed for stable isotopes of C and N (Chapter 4 this Report). Approximately ten shrimp were individually weighed each month using an electronic balance.

Results

The temperature in the ponds ranged from 23.3°C to 35°C and the salinity from 9 ppt to 29 ppt. There were no significant differences in temperature, salinity, pH or the different forms of nitrogen between the ponds (Table 2).

The pond surface water temperature increased as much as 5°C between dawn and the afternoon. On most days, the water temperature in different pond locations and depths was within one or two degrees. However, on one occasion the surface water of both the platform and the ditch was 5°C warmer than the bottom water in the ditch. This contrasts with previous records of rice–shrimp pond conditions, where it was common for the bottom ditch water to be significantly cooler than the surface temperature for most of the grow-out season (Minh et al.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Part A of this chapter). Water salinity increased from about 10 ppt at the beginning of January to almost 30 ppt in early March.

Table 2. Water quality parameters in the low, medium and high exchange ponds.

Parameter	Low	Medium	High
Temperature °C	23.3–32.2	23.3–35.0	23.7–32.7
Salinity (ppt)	13.9–29.9	8.7–26.4	9.00–29.9
pH	5.05–8.83	7.17–9.02	6.93–8.63
N-NO_3 (mg/l)	0.01–0.29	0.10–0.20	0.02–0.39
N-NO_2 (mg/l)	0.01–0.07	0.01–0.05	0.01–0.11
N-NH_4 (mg/l)	0.07–0.88	0.20–0.69	0.10–0.92

The concentration of total suspended solids in the pond water was highly variable and ranged from 46 to 267 mgL^{-1} (Table 3). The percentage of inorganic matter varied from 62% to 82% and chlorophyll *a* levels varied from 5.4 to 75.2 μgL^{-1}. There were no significant differences in the mean monthly TSS levels between the ponds.

Table 3. Range in the total suspended solids (TSS), percentage inorganic and organic matter and chlorophyll *a* levels in low exchange, medium exchange and high exchange ponds.

Character	Low	Medium	High
TSS (mgL^{-1})	64.7–249.5	45.9–266.9	64.9–235.6
Inorganic (%)	65.4–81.7	62.2–71.4	67.2–79.1
Organic (%)	15.4–34.6	24.4–39.6	15.9–34.8
Chlorophyll *a*	5.4–33.4	9.3–75.2	4.1–57.6

During the first three months, the average growth rates of the shrimp in the medium exchange pond were more rapid than in the low or high exchange ponds (Figure 1). However, after four months the average weight of individual shrimp was about 23 g in all three ponds. The most pronounced difference between the ponds was in overall yield (Table 4). The highest yield of 132.5 kg/ha was from the low exchange pond and the lowest yield of 10 kg/ha was from the high exchange pond.

Table 4. Variation in stocking density, stocking time, mean final harvest weight and yield of *P. monodon* grown in low, medium and high water exchange ponds.

Parameters	Low	Medium	High
Stocking density (Shrimp/m^2)	3.0	3.0	1.5
Stocking time (days)	69.0	70.0	69.0
Mean final wt (g)	23.0	23.1	22.6
Yield (kg/ha)	132.5	109.14	10.0

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

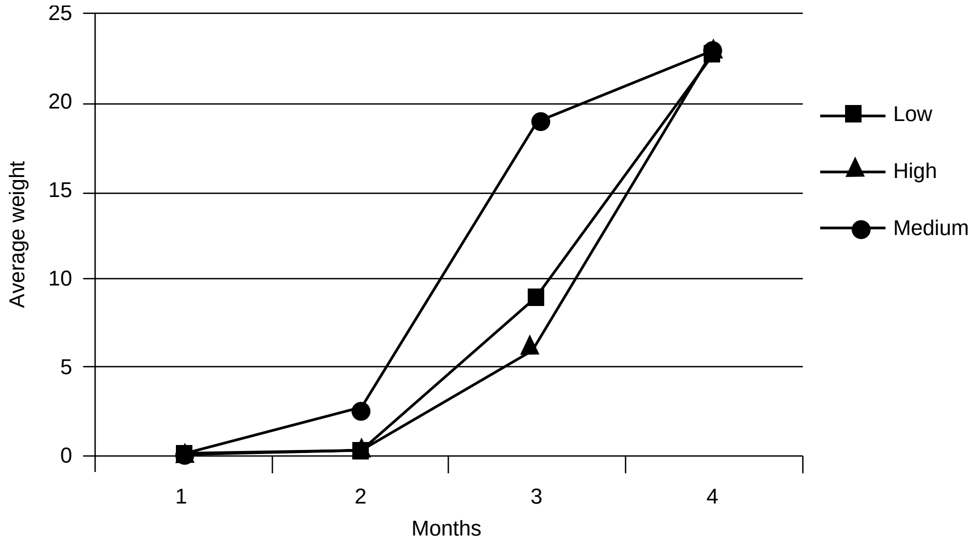

Figure 1. Growth rates of *P. monodon* in low, medium and high water exchange ponds.

Discussion

This study has highlighted a number of challenges in attempting to assess the potential for rice–shrimp farmers to reduce pond water exchange rates without reducing the pond yields of *P. monodon*. In establishing the farm trials, we found that farmers were concerned about their potential loss of income due to reduced recruitment of natural shrimp. One of the farmers abandoned a low-exchange treatment because of this concern. The concerns about loss of income from natural shrimp were exacerbated by the shortages in supplies of *P. monodon* postlarvae (Chapter 5 this Report).

During the study, one of the farmers encountered serious problems with disease resulting in very high shrimp mortality. Analysis of moribund shrimp from the farm revealed the presence of a known viral pathogen (white spot virus syndrome). Little is known about the extent of viral infection of the farmed shrimp in this region, or the principal disease vectors. This lack of knowledge is clearly a serious impediment to conducting meaningful experiments on farm management options. An effective postlarval viral health screening strategy is required. This would reduce the risks of field studies being compromised by the effects of diseases. The problems with viral disease that were encountered in this study were one of the principal reasons for establishing the shrimp viral screening facility at Can Tho University, facilitated with funding support provided from ACIAR.

Despite the problems that we encountered, our preliminary observations suggest that further fully replicated studies of the effects of reducing water exchange on sediment accumulation in the ponds and total shrimp yields would be of considerable value.

CHAPTER 4

Dominant sources of dietary carbon and nitrogen for shrimp reared in extensive rice–shrimp ponds

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Abstract

Stable isotope analysis was used to determine the sources of dietary nitrogen and carbon for shrimp in rice–shrimp farms in the My Xuyen and Gia Rai districts, Vietnam. Most of the carbon input to the ponds in the My Xuyen District was in the form of homemade feed, comprising rice, rice bran, cornmeal and fishmeal. The homemade feed had low nitrogen levels and contributed little to the protein requirements of the shrimp at all three farms. In contrast, the commercial feed (CF1) used at My Xuyen farms was more nutritionally balanced than the homemade feed, but was only added to ponds in low quantities early in the growth season. Two of the three farms in the Gia Rai District used commercial feed (CF2); the third relied solely on the natural biota to supply the nutritional requirements of the shrimp. The commercial feed appeared to contribute little to the nutritional needs of the shrimp. In contrast, the biota caught with beam trawls in the second half of the season at My Xuyen farms and the seston at Gia Rai farms had C:N ratios and $\delta^{13}C$ values similar to the shrimp, and may have contributed to shrimp nutrition. The C:N ratios of the sediment were high relative to the shrimp, and it is unlikely that biota in the sediment contributed significantly to shrimp nutrition. In terms of management implications, this study suggests that there is little nutritional value in feeding shrimp homemade feed with the current formulations. The natural biota appeared to contribute significantly to shrimp nutrition, and there is potential for a greater contribution by the addition of fertiliser high in nitrogen to increase the microalgal biomass and subsequently natural feeds available for shrimp. However, this would be more effective if the turbidity in the water column were decreased, providing more light for phytoplankton, periphyton and benthic microalgal growth.

IN SALINE-AFFECTED areas of the Mekong Delta, the traditional wet season rice crop is often supplemented with a dry season crop of farmed shrimp (Tran et al. 1999). The adoption of shrimp as a second crop in the dry season has resulted in significant income gains for some farmers (Tran et al. 1999; Brennan et al. 2000).

In the rice–shrimp system, the shrimp farmers use a variety of different feeding practices and diets. These range from relying on the natural biota as the only food source, to feeding with homemade formulations or feeding with expensive commercial feeds. A recent economic analysis of representative rice–shrimp farms has indicated that the addition of homemade feeds, particularly if the main ingredients are rice and rice bran, has little impact on production (Brennan et al. 2000). One implication of these results is that the dietary requirements of the shrimp may be met by natural pond biota rather than the homemade feeds.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Organic matter from different origins has distinct nitrogen and carbon isotopic compositions. These compositions can be used to identify the food sources for shrimp and define the trophic structure of aquatic food webs (Peterson and Fry 1987). In order to examine this issue we used stable isotope analysis to determine the sources of dietary nitrogen and carbon for *Penaeus monodon* grown in rice–shrimp ponds.

Methods

Three farms in My Xuyen District and three farms in Gia Rai District were studied in the years 1998 and 2000 respectively. The ponds were stocked with *P. monodon* at stocking densities between one and three animals m^{-2} (Table 1). Other shrimp species were also present in some ponds in lesser numbers, having been recruited from the river during pond flushing events. These are referred to as 'wild shrimp'. After a period of 9 to 16 weeks, *P. monodon* was harvested from ponds, and individual shrimp weights and total weights were recorded (Table 1). In the case of Gia Rai ponds, viral disease problems necessitated an early harvest, which is reflected in the low harvest biomass.

There were two main types of feed added to the ponds: commercial feed and homemade feed (Table 1). The homemade feed, made of fishmeal, ricebran, rice and cornmeal, was only used in My Xuyen ponds.

Table 1. Design and management of farms in My Xuyen and Gia Rai districts.

	My Xuyen			Gia Rai		
	Farm 1	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**	**Farm 6**
P. monodon						
Stocking density (m^{-2})	1.6	1.6	1.6	3	3	1
Grow-out period (wk)	16	16	16	9	9	9
Harvest (kg)	340	440	400	19	160	130
Survival (%)	83	87	94	10	23	57
Pond size (ha)	1	1.3	1	1	1.2	1.4
Feed						
Commercial feed (kg)						
CF1	67	67	75	—	—	—
CF2	—	—	—	102	206	—
Homemade feed (kg)						
Rice	400	400	300	—	—	—
Ricebran	125	125	150	—	—	—
Cornmeal	50	50	27	—	—	—
Fishmeal	600	600	400	—	—	—

Ponds were sampled on three occasions during the shrimp growth season in My Xuyen District: one (early), two (mid) and three (late) months after stocking; and on two occasions in Gia Rai District: one (early) and two (mid) months after stocking. Samples for $\delta^{15}N$, $\delta^{13}C$, C and N analysis were taken of the natural biota, commercial and homemade feed, and shrimp in

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

each pond during these times. The seston was sampled using a plankton net (mesh size 100 µm) towed 20 m in the ditch. Beam trawl samples were also taken by towing a trawl (mesh size 1000 µm) across both the ditch and the platform. Sediment cores were taken in the ditch.

Results and discussion

The carbon to nitrogen (C:N) ratios and $\delta^{13}C$ values of shrimp were compared with the feed sources in three ponds in both My Xuyen and Gia Rai districts. The C:N ratios and $\delta^{13}C$ values of the homemade feeds used in My Xuyen farms varied significantly between sampling occasions (Fig. 1). In all cases, C:N ratios and $\delta^{13}C$ values were substantially different from both *P. monodon* and the wild shrimp. These results suggest that the homemade feed was providing little nutrition for the shrimp.

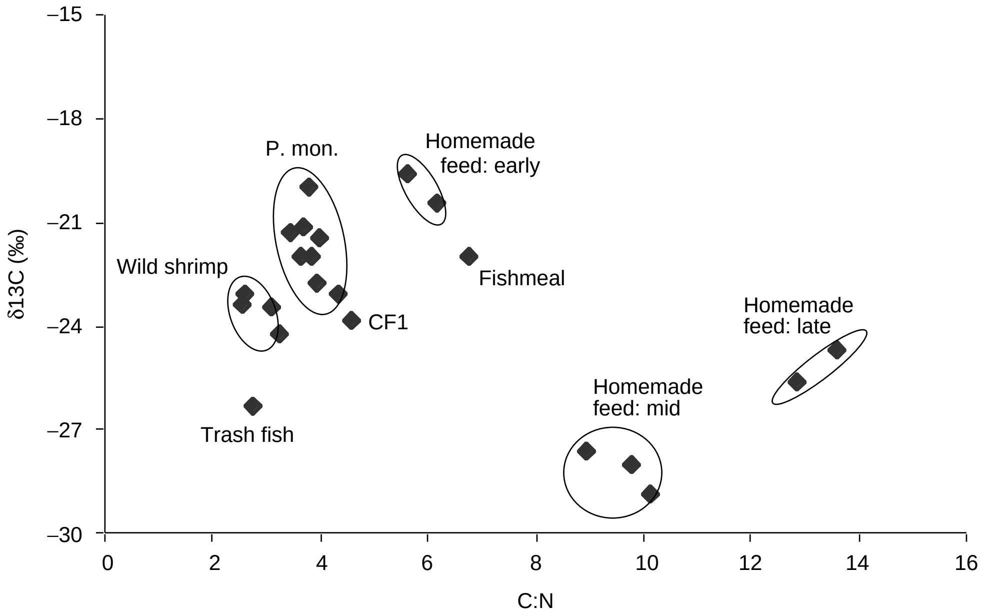

Figure 1. $\delta^{13}C$ (‰) and C:N ratios for shrimp and feed at three farms in My Xuyen District. P. mon. = *Penaeus monodon*; CF1 = commercial feed; early, mid and late denote times in the shrimp growth season.

The commercial feed (CF1) used in My Xuyen District had an isotopic signature and C:N ratio similar to that of the shrimp (Fig. 1). In contrast, the $\delta^{13}C$ isotopic signature and C:N ratio of commercial feed (CF2) used in Gia Rai farms was consistently different from that of shrimp (Fig. 2). Commercial feeds can vary considerably in quality and ultimately in the nutritional benefit to the shrimp. The greatest benefit is likely to come from using high-quality, high-cost feeds. Despite this, previous studies have shown that only 20 to 35% of the nitrogen added to shrimp ponds as commercial feed is retained by the animals at harvest (Briggs and Funge-Smith 1994; Páez-Osuna et al. 1997; Preston et al. 2000). Therefore, most of the high-cost nitrogen is ultimately wasted.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

The isotopic signatures for the natural biota were compared with the shrimp to determine which biota were contributing to shrimp nutrition in the ponds. The C:N ratios and $\delta^{13}C$ values of the biota caught in beam trawl, i.e. epibenthos, in My Xuyen farms were generally similar to the shrimp (Fig. 3). In Gia Rai ponds, the C:N ratio and $\delta^{13}C$ values of shrimp were similar to seston and beam trawl samples (Fig. 2). The C:N ratio of the sediment samples were much higher.

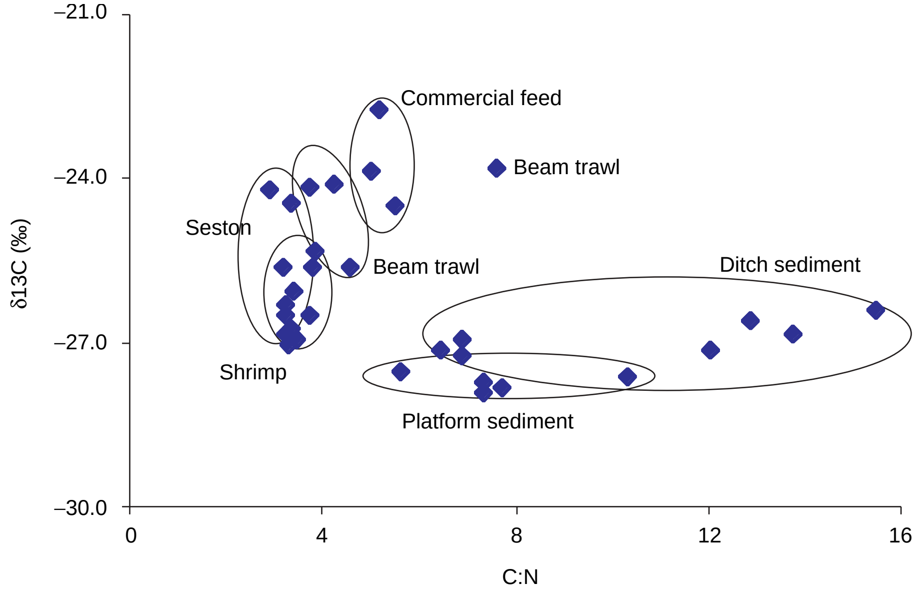

Figure 2. $\delta^{13}C$ (‰) and C:N ratios for shrimp, natural biota and feed at three farms in Gia Rai District.

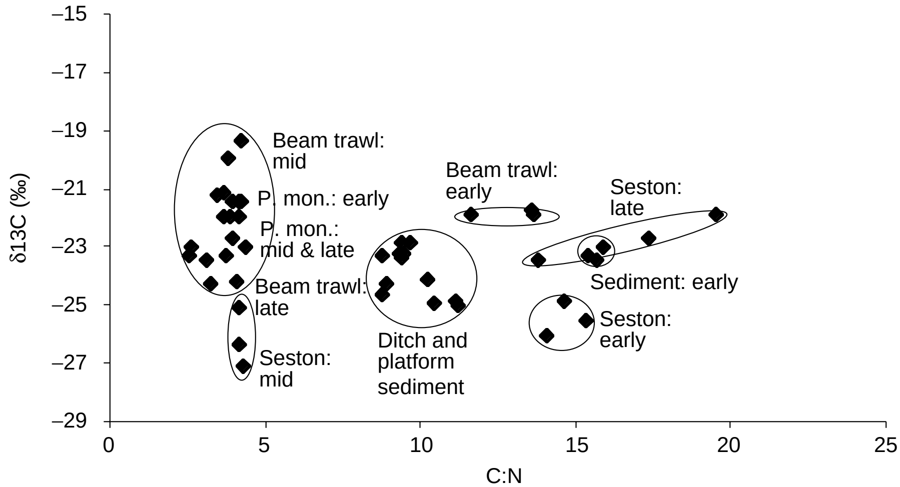

Figure 3. $\delta^{13}C$ (‰) and C:N ratios for shrimp and natural biota at three farms in My Xuyen District. P. mon. = *Penaeus monodon*; early, mid and late denote times in the shrimp growth season.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

The results suggest that the natural biota was playing a major nutritional role in shrimp nutrition. This is further verified by the fact that the shrimp production was as high at the farm with no feed addition as at the farms with feed addition. The significant contribution by the natural biota could be further promoted by the addition of nitrogen fertiliser, since the biota had a high C:N ratio early in the season. However, the high turbidity in these ponds, due to inorganic particles in the water (Truong et al. this Report, Tran Thi Tuget Hoa et al. this Report), was likely to be inhibiting the growth of algae and hence the natural biota. Therefore, the addition of fertilisers to stimulate the growth of the algal community, and hence the higher trophic levels, would be more effective if turbidity levels in the ponds were reduced.

The use of homemade feeds to feed either shrimp or the natural biota does not appear to be worthwhile unless the formulations are changed significantly. Even if this were done, the water stability of these feeds is likely to be low compared with commercial feeds, resulting in the release of significant amounts of nutrients. This is an inefficient use of resources and impacts on the adjacent waterways.

In conclusion, the natural biota appeared to provide the bulk of the dietary nitrogen and carbon requirements of *P. monodon* in rice–shrimp ponds. Commercial feeds also provided a nutritional source; however, the benefits depended on the formulation used. Homemade feeds were of limited value.

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Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 5

Shrimp hatchery production in two coastal provinces of the Mekong Delta

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Abstract

The status of shrimp hatchery production in the coastal provinces of the Mekong Delta, Vietnam, was investigated in late 1997. The survey showed that the three species of shrimp used as broodstock were *Penaeus monodon*, *P. merguiensis*, and *P. indicus*. The survey also revealed that the number of hatcheries had increased very rapidly over the previous decade. In 1997, there were 134 hatcheries that produced a total of 217.5 million postlarvae. A further 1.7 billion postlarvae were imported from the central provinces to the region. The dominant source of postlarvae was from wild *P. monodon* broodstock. Local wild-harvest *P. monodon*, *P. merguiensis*, and *P. indicus* broodstock were a significant source of postlarvae. Local pond-reared *P. monodon*, *P. merguiensis*, and *P. indicus* broodstock were a minor source, with lower reproductive output than wild broodstock. The annual average production of postlarvae from local hatcheries ranged from 2.6 million (in Bac Lieu) to 3.6 million (in Ca Mau) for *P. monodon*; and from 7.6 million (in Ca Mau) to 9.8 million (in Bac Lieu) for *P. merguiensis* and *P. indicus*. Average net income of 23.9 million dong and 130.2 million dong were obtained for each hatchery in Bac Lieu and Ca Mau provinces respectively. The results of the survey revealed a critical shortage in supplies of postlarvae for stocking shrimp farms in the Mekong Delta region.

TRADITIONALLY, SHRIMP FARMERS in the Mekong Delta have used extensive shrimp-farming methods. However, over the past decade, there has been rapid expansion of shrimp farming coupled with a diversification of farming systems. The farming systems now include improved–extensive culture, semi-intensive culture, intensive culture, mangrove–shrimp, rice–shrimp and artemia–shrimp systems. Improved–extensive shrimp culture is the most widely practised, with average productivity of 200–600 kg/ha/year. In 1997, the total area of shrimp ponds in the Mekong Delta was estimated to be 185 700 ha with a total production of 48 665 tonnes. Rice–shrimp farming comprised a significant component of this production. The nature of the rice–shrimp system is described elsewhere in this report.

The first shrimp reproduction and hatchery trials in Vietnam were conducted in the northern provinces from 1971 to 1974. Commercial-scale hatchery production commenced in the central provinces in 1985. The first reproduction and hatchery trials within the Mekong Delta were conducted at Can Tho University in 1988. These trials facilitated the development of the hatchery industry in the region. The objective of the current study was to quantify hatchery production in the two principal shrimp-hatchery provinces in the Mekong Delta region and to identify the key factors affecting the sustainability of postlarval supplies to the region.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Data and methods

This study was conducted in late 1997 in the provinces of Bac Lieu and Ca Mau where most of the shrimp hatcheries in the Mekong Delta region were located. A survey of 18 hatcheries in Bac Lieu and 16 hatcheries in Ca Mau was conducted. This involved direct interviews with the hatcheries workers, technicians and managers. Additional information on shrimp hatcheries and shrimp production in the Mekong Delta was also collected from annual reports of the provincial Department of Fisheries.

Results

Shrimp culture and shrimp seed production in the Mekong Delta

The total annual shrimp production from the seven coastal provinces of the Mekong Delta was 47 095 tonnes from 167 824 ha in 1993; 38 795 tonnes from 212 689 ha in 1995 and 48 665 tonnes from 185 700 ha in 1997. Ca Mau (formerly known as Minh Hai) and Bac Lieu provinces were the main production areas.

In 1992, Ca Mau Province had 15 hatcheries producing 140 million postlarvae; by 1997 this had increased to 110 hatcheries producing 200 million postlarvae, making postlarval production an important industry in the region. Tien Giang, Ben Tre, Soc Trang and Kien Giang provinces were minor production areas with only one to four hatcheries in each province in 1997. The demand for postlarvae could not be met by local supplies and most postlarvae were imported from the central provinces to local nursery stations. Most of the nursery stations were located in Ca Mau, which collectively imported 1.4 million postlarvae in 1997. The central provinces of Khanh Hoa, Binh Thuan, Ninh Thuan, Vung Tau, Da Nang, Phan Rang and Phan Thiet were the main suppliers of postlarvae to the Mekong Delta.

Hatchery ownership and staffing

Almost all of the hatcheries surveyed belonged to private households or joint stockholders. All the hatcheries were operated by those with either tertiary education or previous technical experience. In Ca Mau and Bac Lieu survey hatcheries, 25% and 39% respectively, were operated by those with tertiary training (BSc). The rest were run by technicians who had previously worked with tertiary-trained hatchery managers or had attended short training courses in hatchery techniques. The results also showed that the hatchery operators in Bac Lieu had worked in hatcheries for an average of 6.5 years (ranging from 3 to 16 years), compared to an average of 3 years in Ca Mau (ranging from 1 to 10 years). This is probably a reflection of the fact that many of the hatcheries surveyed in Bac Lieu had been there since the early 1990s, whereas the hatcheries in Ca Mau started operating from 1994.

Technical aspects

Hatchery location

The majority of hatcheries surveyed in Bac Lieu province were in Gan Hao town, on the bank of the river mouth about 2 km from the sea. The advantages of this location included easy access for broodstock delivery via river or road, electricity supply and telephones. The disadvantages were the risks of water pollution, particularly from ships, boats and domestic sewage. In the rainy season, very turbid water and low salinity (10–15 ppt) were a major impediment to hatchery

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

production. Furthermore, the juxtaposition of most hatcheries increased the risk of pollution and disease transmission.

Most of the hatcheries surveyed in Ca Mau Province were on the banks of a large river in Nam Can area, about 20 km from the sea. Although nearly 100 hatcheries had been established in the district, the density was much lower than in Ganh Hao in Bac Lieu. Some of the hatcheries in Ca Mau Province (18.9% of those surveyed) had no access to electricity or telephones. As in Bac Lieu, salinity in Ca Mau was low in the rainy season and the water was very turbid. Details on hatchery distribution are presented in Table 1.

Table 1. Sites of the survey hatcheries in the Bac Lieu and Ca Mau provinces.

Province	Area	No. of hatcheries (km^{-2})	Distance to the nearest hatchery (m)	Distance to the sea (km)	Salinity (ppt)
Bac Lieu	Ganh Hao	35 (5–60)	45 (3–200)	2 (1–3)	11–30
Ca Mau	Nam Can	13 (6–20)	142 (1–500)	20 (12–30)	15–31

Hatchery characteristics

The mean sizes of the Bac Lieu and Ca Mau hatcheries were similar, with an average area of 204 m^2 and 214 m^2 respectively. The largest of the survey hatcheries in Ca Mau had an area of 720 m^2 and in Bac Lieu 480 m^2. The hatcheries were usually separated from the houses, but contained a small living room for workers. The hatcheries were constructed from a variety of materials including concrete, brick, wood, thatch, nylon and tin. Very few of the hatcheries surveyed had adjacent ponds for use as postlarval nurseries.

In both Bac Lieu and Ca Mau, sediment/reservoir tanks were important for settlement of the turbid river water and for storage during unfavourable phases of the tide. The total volume of sediment/reservoir tanks was similar for hatcheries surveyed in Bac Lieu and Ca Mau (Table 2). The reservoir tanks were usually half buried in the ground with a roof covering. Following settlement and storage, hatchery water was usually filtered. The most common strategy was to use a complex of one to two small tanks of 2–3 m^3 containing layers of sand, rock, coral and activated charcoal.

The majority of the surveyed hatcheries (56% in Bac Lieu and 94% in Ca Mau) had separate broodstock tanks with an average volume of 3.0 m^3 (Table 2). Most of the hatcheries had between one and three broodstock tanks. Most of the hatcheries also used larval-rearing tanks as spawning tanks, because of lack of space. Two to three tanks of 3–4m^3 were normally used for this purpose.

Larval–rearing tanks in the hatcheries of both provinces were similar. These consisted of 8–20 tanks (average 14 tanks) of 4 m^3 in volume (size 2m × 2m × 1m). Generally, the rearing tanks were small enough for easy management. The tanks were placed in two rows and all tanks were indoors.

Algal tanks were found in all the hatcheries that were surveyed in Bac Lieu (100%), but only in 62% of the hatcheries in Ca Mau. These usually consisted of eight to ten tanks of 1 m^3.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

However, many of the hatcheries in the survey are now using artificial feed and dried algae instead of fresh algae. Only 44% of hatcheries had freshwater; this was generally stored in one to two tanks of 2–3 m^3.

Table 2. Average number and volume of different tanks in the shrimp hatcheries surveyed.

Tanks	Bac Lieu			Ca Mau		
	Mean no.	Volume (m^3)/ tank	Total volume	Numbers (item)	Volume (m^3)/ tank	Total volume
Sediment/reservoir	3.28	22.50	64.0	3.4	17.0	51.8
Filter	1.50	2.80	4.1	1.7	2.9	5.3
Broodstock	2.10	3.30	7.0	2.4	2.9	6.6
Spawning	2.60	4.40	10.8	2.5	3.2	7.5
Larval	14.00	4.10	58.1	14.6	4.0	59.0
Algal	9.00	0.99	8.7	8.6	1.0	8.4
Freshwater	1.25	2.40	2.9	1.0	2.6	2.6

Most hatcheries were equipped with air blowers, compressors, generators and water pumps. However, other basic equipment such as salinometers, thermometers, water quality test kits, microscopes and microbalances were lacking in many hatcheries (Table 3).

Table 3. Percentage of different facilities in survey hatcheries in Bac Lieu and Ca Mau.

Item	Bac Lieu	Ca Mau
Blower/compressor	100.00	100.00
Generator	100.00	88.89
Pump	100.00	100.00
Boat	0.00	50.00
Salinometer	88.89	87.50
Thermometer	55.56	77.78
Microscope	5.56	31.25
Microbalance	5.56	50.11

Broodstock culture

In the past, the shrimp farming industry in the Mekong Delta relied mainly on locally captured, mature *P. merguiensis* and *P. indicus* wild broodstock. However, at the time of this survey most farmers had switched to *P. monodon*, principally because of the higher prices received for this species.

The results of the survey in Ca Mau and Bac Lieu showed that *P. monodon* females reared in production ponds had an average size of between 120 g and 150 g, whereas the average size of wild broodstock was between 250 g and 300 g (Table 4). Banana shrimp (*P. merguiensis*) and Indian shrimp (*P. indicus*) were mainly from local fishing grounds. The average size of females of these species was between 30g and 100g.

Most hatcheries initially treated broodstock with formalin at a concentration of between 15 ppt and 20 ppt. The broodstock were usually maintained in cement tanks with an average density of 4 m^{-2}, and with a ratio of one male to three to five females. In some cases, the operators of the hatcheries surveyed maintained males and females separately. Where sexes were maintained separately, artificial insemination was used. The spermatophores were transferred from males to females when the female had just moulted. Various methods of eyestalk ablation were applied in order to induce spawning.

The broodstock were fed with squid, shrimp, blood cockle, hermit crab and pig liver. Feeding frequency was every 3–4 hours. The daily feeding rate averaged of 9.8% of body weight in Ca Mau hatcheries and 12.73% of body weight in Bac Lieu. After four to seven days of culture, the broodstock are ready to spawn. The average survival rate of the broodstock was between 44% and 55%. The spawning rate was between 52% and 57%. The average number of nauplii produced per spawner ranged from over one million from wild-caught *P. monodon* broodstock to 200 000 from wild-caught *P. merguiensis* and *P. indicus*.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 4. Characteristics of broodstock culture of shrimp in the Bac Lieu and Ca Mau survey hatcheries.

Characteristics	Bac Lieu	Ca Mau
Culture species	*Penaeus monodon*, *P. merguiensis*, *P. indicus*	*P. monodon*, *P. merguiensis*, *P. indicus*
Broodstock sources	Local sea, local ponds, central province sea	Local sea, local ponds, central province sea
Broodstock size (g)		
P. monodon (ponds)	135 ± 28	126 ± 16
P. monodon (sea)	271 ± 54	248 ± 66
P. merguiensis, *P. indicus*	67 ± 28	60 ± 17
Chemical treatment	Formalin (15 ppm)	Formalin (20 ppm)
Eye ablation		
Pinching	80%	31%
Slitting and crushing	0%	31%
Cauterizing	20%	0%
Tying	0%	37%
Culture density (ind./m^2)	4	4.5
Male:female ratio	1:3	1:5
Feed type	Squid, shrimp, blood cockle, hermit crab, liver	Squid, shrimp, blood cockle, hermit crab, liver
Feeding rate (%BW)	13	10
Water depth (m)	0.42	0.3
Water exchange (frequency/day)	1	1
Exchange rate (%/time)	75	75
Tank cover	Yes	Yes
Culture duration (day)	5	6
Survival rate (%)	52	44
Spawning rate (%)	52.5	57.5
Number of spawning/spawner	4	3.3
Millions of nauplii/spawn		
P. monodon (ponds)	0.52 ± 0.19	0.55 ± 0.66
P. monodon (sea)	1.04 ± 0.34	1.06 ± 0.50
P. merguiensis, *P. indicus*	0.20 ± 0.11	0.22 ± 0.30

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Larval culture

In Bac Lieu, 76% of the hatcheries produced *P. monodon* and 59% produced *P. merguiensis* and *P. indicus*. In Ca Mau, 100% of the hatcheries produced *P. monodon* and 20% produced *P. merguiensis* and *P. indicus*.

Larval rearing densities were lower for *P. monodon* than for *P. merguiensis* and *P. indicus* (Table 5). The survey revealed that the practice of using fresh algae for feeding larvae has largely been replaced by the use of dried algae. This is because algal culture is a very labour-intensive work and it is difficult to maintain cultures during the rainy season. Dried algae (*Spirulina* sp.) combined with artificial feed (N-0, N-1, N-2, Lanxy, Lypac, ABS) were the main sources of nutrition for the early feeding stages (zoea). Artemia was the dominant feed source for the mysis stages. In all the hatcheries, artemia cysts were decapsulated with chlorine (100 ppm for 30 min.) before incubation. Artemia were also fed to postlarvae, which were also fed 'custard' a mixture

Table 5. Characteristics of larval rearing in the hatcheries surveyed.

Characteristics	Nauplii	Zoea	Mysis	Postlarvae
Stocking density (ind./L)				
P. monodon	161.5			
P. indicus and *P. merguiensis*	223.0			
Feeding regimes:				
Fresh algae	None	Supplement		
Dry algae (g/m^3/time)	None	0.4		
Artificial feed (g/m^3/time)	None	0.5	1.12	1.20
Artemia (ind/mL)	None	Supplement from Z_3	0.75	1.04
Custard (g/m^3/time)	None	None	None	5.19
Frequency (time/day)		8–12	8–12	4–8
Water salinity (ppt)				
P. monodon	27–32	27–32	27–32	27–32
P. indicus and *merguiensis*	22–30	22–30	22–30	22–30
Water exchange:				
Frequency (day/time)	None	One time at Z_3	2–3	1–3
Exchange rate (%/time)	None	23	26	37
Aeration (air stone/tank)	5	5	5	5
Cover	Black or opaque plastic	Black or opaque plastic	Black or opaque plastic	None
Survival rate (%)				
P. monodon				32
P. indicus and *P. merguiensis*				42

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

of ground shrimp and duck or chicken eggs. However, custard is often replaced by various brands of artificial feed. Larvae were fed eight to twelve times per day, while postlarvae were fed four to eight times per day.

Salinity for larval rearing of *P. merguiensis* and *P. indicus* ranged from 22 ppt to 30 ppt for the survey hatcheries. Salinity levels for *P. monodon* were higher, ranging from 27 ppt to 32 ppt. Water exchange practices varied among the hatcheries surveyed. Some of the hatcheries commenced water exchange at the late protozeal stage (Z-3); others waited until the early postlarval stages. The rearing tanks were usually covered with black plastic.

The average duration of rearing larvae through to the first postlarval stage was 10–12 days. All hatcheries encountered significant problems in larval rearing. The problems that were commonly identified included bacteria, fungus, moulting entrapment and muscle necrosis. None of the hatcheries had the capacity to determine the presence of viral pathogens. Overall the average larval survival rates were 32% for *P. monodon* and 42% for *P. merguiensis* and *P. indicus*.

Transportation

Broodstock were generally transported in Styrofoam containers with five to ten individuals per container (Table 6). Ice was sometimes used to reduce the water temperature during transportation. The broodstock may be kept in these conditions for three days before reaching the hatchery. Broodstock survival rates were high (95%).

Nauplii were usually transported from the central provinces by car, boat or plane. Nauplii were transported at high density in large plastic bags (Table 6). Postlarvae were transported at a lower density in smaller plastic bags. Normally, no ice was used during the transport of nauplii or postlarave, but survival rates were high (95%).

Table 6. Characteristics of shrimp transportation for the survey hatcheries.

Characteristics	Broodstock	Nauplii	Postlarvae
Duration (hrs)	18	13	7
Method	car, boat	Plane, car, boat	car, boat
Bag/pack	Styrofoam containers (0.3m × 0.4m × 0.5m)	Plastic bags (8–10 L water)	Plastic bags (2–5 L water)
Ice	22%	None	None
Density (ind/container)	7		
(ind./liter)		6 518	570
Survival rate (%)	95%	95%	96%

Economic aspects

On average across the survey hatcheries, five to six batches of larvae were reared each year (Table 7). The hatcheries in Ca Mau produced more batches of *P. monodon* and fewer batches of *P. merguiensis* and *P. indicus* compared with the hatcheries surveyed in Bac Lieu. Because of the higher price obtained for *P. monodon* postlarvae, the hatcheries in Ca Mau were found to be generally more profitable than those in Bac Lieu (Table 8).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 7. Average production of postlarvae (millions per year) across survey hatcheries.

Provinces	No. batches/year	*P. monodon*	*P. merguiensis* *P. indicus*
Bac Lieu	5.1 ± 2.8	2.6 ± 2.0	9.8 ± 6.0
Ca Mau	5.5 ± 3.4	3.6 ± 3.0	7.6 ± 7.4

Table 8. Average hatchery shrimp-seed costs and income across survey hatcheries in million VND per year.

	Bac Lieu	Ca Mau
Operating cost	111 ± 37	139 ± 77
Fixed costs	14 ± 4	15 ± 4
Total cost	125 ± 40	154 ± 77
Total income	149 ± 103	284 ± 169
Net income	23 ± 88	130 ± 110

In both provinces, operating costs were much higher than the fixed costs. The dominant average fixed costs were tanks (48%), hatchery house (14%) and land (14%). The dominant average operating costs were feed (36%), broodstock (20%) and labour (18%).

Conclusions and recommendations

The results of the 1997 survey revealed that the shrimp hatchery industry in the Mekong Delta was a dynamic and generally profitable industry. Trained workers or technicians operated the majority of the hatcheries in the survey. The results showed that the production of *P. monodon* postlarvae was more profitable than production of *P. merguiensis* and *P. indicus*. The supply of local broodstock was far too low to meet the demand for postlarvae, and broodstock, nauplii and postlarvae had to be imported from the central provinces which are now the dominant sources of supply. The results suggest that in order to meet the increasing demand for postlarvae, greater investment in the development of increased local supplies of broodstock is required. Since the supplies of wild broodstock from local waters or the central provinces is limited and unpredictable, one potential area for advancement is to improve the reproductive output of domesticated broodstock, especially for *P. monodon* which is the more profitable hatchery species.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 6

Selection of suitable rice varieties for monoculture and rice–shrimp farming systems in the Mekong Delta of Vietnam

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Abstract

The purpose of this paper was to identify suitable rice varieties and compare rice growth and yield in rice monoculture and rice–shrimp systems in the rain-fed saline areas of the Mekong Delta. A series of farm trials was conducted in rice fields in Soc Trang and Bac Lieu provinces during the rainy seasons of 1997 and 1998. The growth and yield results from the experiments provided a measure of the performance of these rice varieties in the rice monoculture and rice–shrimp farming systems. In the 1997 wet season, 12 rice varieties were tested, of which 3 were check varieties. Based on the results from 1997, two promising rice varieties were selected and investigated in the 1998 wet season. A pot experiment was also conducted to test the salinity tolerance of five rice varieties. The field results showed that rice crops performed better in the monoculture system. In the 1997 trials, MTL119 was the best rice variety in both systems, followed by MTL204, MTL205, MTL207 and MTL209. The MTL119 variety performed best in all aspects, including tiller and panicle development, Leaf Area Index (LAI), biomass, nutrient content in leaf, stem and grain, and good grain yield. The short growth duration of 115–117 days of MTL119 also makes it very well suited in rain-fed saline environments. In the 1998 pot experiments, MTL119 grew well in the culture solution with salinity of 3–6 grams per litre. This supports the results from field trials. The MTL195 variety also grew well at the salinity level of 3–6 grams per litre. Both MT119 and IR64 were selected for the 1998 field trials. Several varieties out-yielded IR64; however, this variety was selected for the 1998 trials because of its widespread use in the study area.

ONE OF THE main factors leading to instability in rice cropping in the rain-fed saline areas of the Mekong Delta is the use of long-duration and low-yielding rice varieties that have not been well suited to the saline conditions. In this study, varietal trials were conducted with the aim of identifying more appropriate varieties for the local ecological conditions in the study area. Results from such research can assist in raising the income and living standards of local farm households in the areas affected by seasonal saline intrusion.

The objectives of this research were to:

- compare the growth and yield of rice in rice monoculture and rice–shrimp systems in rain-fed saline areas of the Mekong Delta
- identify suitable rice varieties for rice monoculture and rice–shrimp systems in the rain-fed saline areas of the Mekong Delta.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

Research methods

Field trials

Field trials were conducted in 1997 and 1998 in the districts of My Xuyen in Soc Trang province and Gia Rai in Bac Lieu province. In 1997, 12 rice varieties were tested. This included 9 new varieties and 3 check varieties (Table 1). Varieties selected for trials had short growth duration of 105–120 days. In 1998, field trials were conducted again in both districts with two of the most promising varieties (MTL119 and IR64) from the 1997 trials. MTL119 was selected because of its superior yield performance over the other varieties across sites, and IR64 was used as check because of its wide use by farmers in the project areas. The details of the field trials are outlined in Table 1.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 1. The 1997 and 1998 rice field trials.

Trial Details	Trial 1 (1997)	Trial 2 (1998)
Location	• My Xuyen District in Soc Trang Province • Gia Rai District in Bac Lieu Province	• My Xuyen District in Soc Trang Province • Gia Rai District in Bac Lieu Province
Rice varieties tested	MTL167, MTL195, MTL204, MTL205, MTL206, MTL207, MTL208, MTL209, MTL210	MTL119 and IR64
Check varieties	• MTL119 (common check) • TN128 (local check in Soc Trang) • IR64 (local check in Bac Lieu)	
Farming systems	• Rice monoculture • Rice–shrimp	• Rice monoculture • Rice–shrimp
Experiments	4 experiments were conducted in each district (2 for each farming system)[1]	6 experiments were conducted in each district (3 for each farming system)[2]
Plot size	5 m × 8 m (40 m^2) for each rice variety	5 m × 8 m (40 m^2) for each rice variety
Cropping procedure	• Seedlings were raised on dry beds in Soc Trang and wet beds in Bac Lieu over 20–23 days. • Seedlings were transplanted with 15 by 20 cm spacing and 2–3 seedlings per hill. • Two fertiliser applications were used: 1. Basal (with N:P:K ratio of 40:40:15); 2. Top dressing (at 20 DAT) (with N:P:K ratio of 50:0:15). • No pesticides were used in the experiments. • Crop management throughout the trial depended on each farmer's own practice.	Similar cropping procedure used as in Trial 1

[2]Randomized Complete Block (RCB) Design with three replications was used in the testing.
[3]Randomized Complete Block (RCB) Design with four replications was used in the testing.

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edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Pot experiment

Pot experiments were conducted to test the salinity tolerance of various rice varieties. Five rice varieties — MTL119, MTL167, MTL195, MTL205 and IR64 — were used for testing. MTL167 and MTL195 were selected as representative of low-yielding varieties and MTL205 and MTL119 were selected as representative for high-yielding varieties. Salinity solutions were made at five different concentrations (control (0), 3, 6, 9, 12 g/L). Rice seedlings were planted in each solution at two weeks after germination. Completed Random Design with three replications was used. The plant height and root length were measured at 15 days after treatment and the salinity tolerance was scored based criteria outlined in Table 2.

Table 2. Salinity tolerance rating.

Score	Description
1	Normal plant growth and tillering
3	Plant growth near normal but some reduction in tillering, some leaves discoloured/whitish and rolled
5	Plant growth and tillering reduced, most leaves discoloured or rolled; only a few leaves emerged
7	Plant growth completely ceased; most leaves dry, some plants dying
9	Almost all plants dead or dying

1997 field trial results

The results from the 1997 experiments are a summary of the full set of results from the paper presented at the final ACIAR project workshop in 2000. Note also that in 1997 typhoon Linda (2 November 1997) caused some damage to the rice crops in the experiments, especially in Gia Rai District. The impacts from typhoon Linda pushed saline water into rice fields in the rice–shrimp plots in Bac Lieu at the critical ripening stage, which caused complete crop loss.

Soil and water conditions

The results from the soil analysis showed that the soil quality was generally good at all experiment sites. Relative to the rice monoculture plots, the soil in the rice–shrimp plots had high electroconductivity (EC) values and also had high amounts of available phosphate (P_2O_5). The chemical properties of soils at the experiment sites are summarised in Table 3. In Table 4, the water pH and EC levels at three important stages of rice growth (transplanting, 20 days after transplanting and panicle initiation) are summarised.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 3. Chemical characteristics of soils in 1997 wet season trials (average across sites).

	Soc Trang		Bac Lieu	
Factor	**RM**	**RS**	**RM**	**RS**
pH (1:5)	5.13	4.61	5.35	6.02
EC (ms/cm)	0.42	1.53	1.00	6.35*
N total (%)	0.16	0.14	0.15	0.11
Organic matter (%)	—	3.04	3.32	2.33
P_2O_5 total (%)	0.08	0.06	0.06	0.08
P_2O_5 available (mg/100 g)	4.21	12.52*	2.43	18.36**
K_2O exchangeable (meq/100 g)	0.49	0.45	0.65	1.21**
Al^{3+} (meq/100 g)	0.18	0.50	0.40	0.00
Fe_2O_3 (%)	0.95	0.69	0.50	0.79

* At high level
** Extremely high level

Table 4. Water pH and EC in the rice fields at three growth stages (average across sites).

	Soc Trang				Bac Lieu			
System	**RM**		**RS**		**RM**		**RS**	
Crop stage	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**
Transplanting	7.00	0.60	7.54	0.67	7.57	2.09	7.65	2.02
20 days after transplant	8.02	0.62	7.07	0.78	6.43	0.84	7.24	0.28
Panicle initiation	7.52	0.33	6.60	—	6.14	—	7.25	—

— no data available

Agronomic characteristics

Growth duration

Growth duration of all tested varieties varied from 115 to 120 days, which is about 2 weeks shorter than that of IR42, a common rice variety used in rice–shrimp farming systems in the study area. The short duration varieties are well suited to the short growing season in the areas where the start of the rice-growing season is often delayed due to the time needed for flushing salinity from the soil after the dry season. The short duration also reduces risk of crop loss in abnormal years when the rainy season finishes early.

Plant height

The plant height was lowest on average in monoculture systems in Soc Trang (average of 82 cm) compared to heights in other systems and at other sites. In the rice–shrimp system in Soc Trang, the average height was 102.5 cm. In Bac Lieu the average height was 104 cm for monoculture systems and 92.5 cm for rice–shrimp systems. Among the tested varieties, MTL119 had the highest plant height in both systems and in both districts. The average heights for the other two check varieties, TN128 and IR64, were among the lowest. The results are summarised in Table 5.

Table 5. Plant height in 1997 field experiments.

Variety	Soc Trang		Bac Lieu	
	RM	RS	RM	RS
MTL167	77.0[d-f]	92.3[efg]	97.0[bc]	81.3[d]
MTL195	78.0[c-f]	89.0[fg]	97.3[bc]	87.3[cd]
MTL204	84.7[bc]	110.3[bc]	115.3[a]	100.3[ab]
MTL205	93.0[a]	115.0[ab]	92.3[c]	92.7[bc]
MTL206	80.3[c-e]	96.0[de]	101.7[b]	93.0[bc]
MTL207	80.0[c-f]	116.7[a]	114.0[a]	104.3[a]
MTL208	82.0[bcd]	94.7[ef]	104.7[b]	92.7[bc]
MTL209	87.7[ab]	108.7[c]	114.3[a]	96.0[b]
MTL210	78.7[c-f]	101.3[d]	97.3[bc]	87.0[cd]
MTL119	93.0[a]	116.7[a]	117.3[a]	107.7[a]
TN128	74.3[e]	88.7[g]	96.7[bc]	80.3[d]
IR64	72.7[f]	96.0[de]	100.3[bc]	87.3[cd]
Mean	81.8	102.1	104.0	92.5
F-test	**	**	**	**
CV (%)	4.8	3.2	4.1	4.7

F-test: significant difference between varieties; **: significant at 1% level.
Means followed by a common letter are not significantly different at 5% level by DMRT.
CV is the coefficient of variance for each experiment.

Tiller number

The tiller number was highest in monoculture systems in Soc Trang (average of 468 tillers/m^2) and lowest in rice–shrimp systems in Bac Lieu (average of 355 tillers/m^2). MTL119, MTL167 and the two local check varieties (TN128 and IR64) ranked the best in maximum tiller number among tested varieties.

Rice leaf area index (LAI)

Similar to the tiller number, the LAI increased from transplanting to the panicle initiation stage in monoculture in Soc Trang, and up to flowering stage at all other sites. At the same growth stages, the LAI of rice in rice monoculture crops was higher than rice in rice–shrimp crops. MTL205 had the highest LAI in Soc Trang; however, in Bac Lieu the LAI for this variety was the lowest among tested varieties.

Dry biomass of rice (tonne/ha)

The biomass of rice plants increased from transplanting to flowering stage at all experiment sites. In general, at the same growth stages, the biomass of rice plants in the monoculture system was higher than that in rice–shrimp systems. Among tested varieties, MTL119 had the highest

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

biomass in the rice–shrimp systems of Soc Trang and Bac Lieu and in the rice monoculture system in Bac Lieu. In the rice-monoculture trials in Soc Trang, MTL119 did not perform as well compared to the other varieties (MTL205 and MTL167).

Nitrogen content in rice plant

The nitrogen content in the rice leaves for all varieties gradually decreased from transplanting to harvesting. There was not much difference between the tested varieties. In the Soc Trang trials, nitrogen content in the rice leaves of five tested varieties (MTL167, MTL205, MTL119, TN128 and IR64) in the rice monoculture trials were higher than those in the rice–shrimp system from 20 days after transplanting (DAT) to flowering. The differences, however, reduced gradually in the later growth stages of rice. In contrast, in Bac Lieu at the same growth stages, the nitrogen content in rice leaves in rice–shrimp trials was higher than that in the monoculture system.

Yield and yield components

Due to saline water intrusion into the field in the late stages of the rice crop (from flowering to harvesting), the rice in the rice–shrimp system in Bac Lieu was totally destroyed.

Number of panicles per square metre

There was no significant difference in the number of panicles among varieties in the monoculture systems or the rice–shrimp systems. However, in the trials the varieties that did the best of the 12 tested were MTL195, MTL204, MTL206, MTL209, MTL119 and TN128.

Number of filled grains per panicle

The average number of filled grains/panicle in the trials was relatively low across all sites and varieties. However, MTL208 and MTL 210 were among the best varieties in both the Soc Trang and Bac Lieu trials. MTL206 also did relatively well in the Soc Trang trials.

Overall, the three check varieties (MTL119, TN128 and IR64) did not perform well in terms of this criterion, although in the Soc Trang rice monoculture trials, IR64 was one of the better performing varieties.

Grain weight

The results showed that 1000-grain weight did not vary much across sites (average 25–26 g/1000 grains). However, there was a significant difference among varieties. MTL119, MTL204 and MTL207 had larger grains while the two check varieties, especially TN128, had smaller grains.

Grain yield

In the trials in Soc Trang there was a significant difference in grain yields among varieties in the rice–shrimp system; however, the variation across varieties in the monoculture trials was not statistically significant. In the rice monoculture trials in Bac Lieu there was significant variation found across the test varieties. The average grain yield in the Bac Lieu rice monoculture trials was fairly high (4.86 tonne/ha) in comparison to the monoculture trials in Soc Trang where yields averaged 3.66 tonne/ha.

Overall MTL119 was found to have the highest grain yield across all experiment sites, followed by MTL204, MTL205, MTL207 and MTL209. The two local check varieties were in the low-yielding group, especially in the rice–shrimp system in Soc Trang (3.9–4.0 tonne/ha).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 6. Grain yield (tonne/ha) of 12 rice varieties by locations and conditions in 1997 wet season trials.

	Soc Trang		Bac Lieu	
Variety	**RM**	**RS**	**RM**	**RS**
MTL167	3.54	3.77[d]	3.84[e]	—
MTL195	4.24	4.57[c]	4.02[de]	—
MTL204	3.68	4.85[abc]	5.89[a]	—
MTL205	4.23	5.24[ab]	4.07[de]	—
MTL206	3.86	4.97[abc]	4.70[bcd]	—
MTL207	3.33	5.07[abc]	5.20[abc]	—
MTL208	3.63	4.74[bc]	4.96[bc]	—
MTL209	3.41	4.90[abc]	5.32[ab]	—
MTL210	3.34	3.83[d]	4.47[cde]	—
MTL119	3.97	5.34[a]	5.82[a]	—
TN128	3.09	3.87[d]	5.22[abc]	—
IR64	3.57	3.96[d]	4.86[bc]	—
Mean	3.66	4.59	4.86	
F-test	ns	**	**	
CV (%)	19.50	6.40	8.60	

** significant at 1% level.
ns: not significant.
Means followed by a common letter are not significantly different at 5% level by DMRT.

Evaluation of growth and yield of two selected rice varieties in monoculture and rice–shrimp systems in 1998 wet season

General information

Many difficulties were encountered in the 1998 trials in Bac Lieu due to heavy droughts and saline intrusion. Most of the rice plants in all three rice–shrimp fields in Bac Lieu and one rice monoculture field partly died 15 to 17 days after transplanting. In My Xuyen District, heavy rains and a rice-bug attack affected the rice in the monoculture system at the flowering stage, resulting in a low percentage of filled grains and poor grain filling. One field in particular was heavily destroyed by the rice-bug, which caused late flowering in comparison with other fields.

Soil and water conditions

Details of the soil and water conditions in the fields of the 1998 trials are outlined in Table 7. Soil salinity was high in the rice–shrimp fields in Bac Lieu (2.11 ms/cm) but in rice monoculture fields salinity did not present a problem. The soil nitrogen and soil phosphate varied from low to high across experiment sites. Aluminium exchange was low at all sites. Iron (free iron) varied from low to medium across sites, and potassium exchange was high in most of the fields.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 7. Chemical characteristics of soils in 1998 wet season trials (averages across experiments).

	Soc Trang		Bac Lieu	
	RM	RS	RM	RS
pH (1:5)	5.36	4.98	4.88	5.62
EC (ms/cm)	0.58	1.40	0.73	2.11
N total (%)	0.12	0.17	0.14	0.11
P_2O_5 total (%)	0.08	0.07	0.08	0.10
P_2O_5 available (mg/100 g)	4.81	7.80	4.79	21.04*
K_2O exchangeable (meq/100 g)	1.12	1.42	0.99	1.99*
Al^{3+} (meq/100 g)	0.03	0.15	0.42	0.00
Fe_2O_3 (%)	0.50	0.91	0.57	0.83

* At a high level.

Agronomic characteristics

Growth duration

Growth duration of MTL119 and IR64 varied from 115 to 120 days. This was very well suited to the short growing season in the study area.

Plant height

The plant height of the selected rice varieties varied across test sites and farming systems, although in general, the plant height of MTL119 was higher than that of IR64. In the Soc Trang trials, the plant height of rice in the rice–shrimp system was higher than in the monoculture system. This was the opposite in the Bac Lieu trials due to poor growth in rice–shrimp fields. The average plant heights in the 1998 trials for MTL119 and IR64 for the two systems are shown in Figures 1a and 1b.

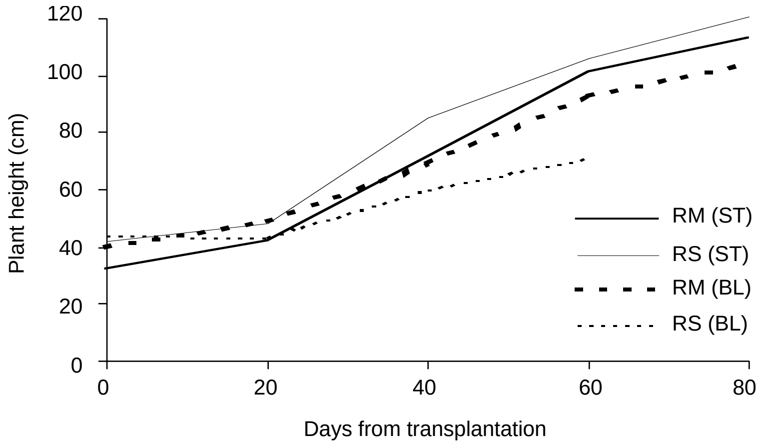

Figure 1a. Plant height of MTL119 (1998).

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edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

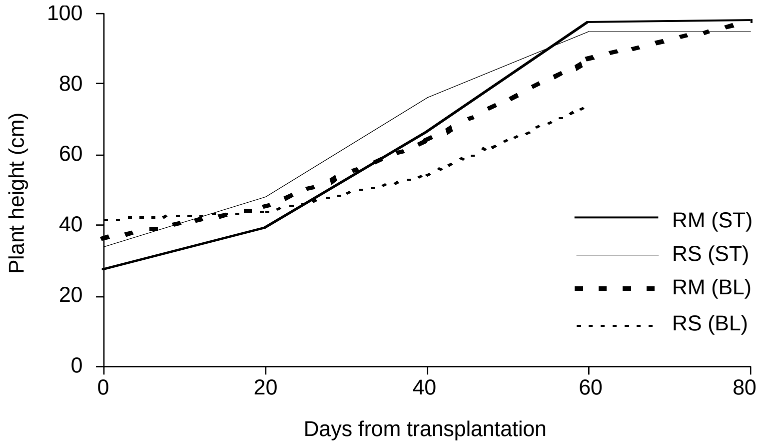

Figure 1b. Plant height of IR64 (1998).

Tiller number

In normal conditions the tiller number (per m^2) of rice increased after transplanting and reached maximum values at panicle initiation (PI) stage. However, in the rice–shrimp trials in Soc Trang and in all trials in Bac Lieu, tiller production continued after PI stage. It is thought that this was due to a delay in plant development caused by salinity stress. The tiller number/m^2 of MTL119 was higher than that of IR64 in both systems. The results are summarised in Table 8.

Table 8. The tiller number/m^2 of rice varieties in 1998 wet season trials.

Rice variety per system	Soc Trang					Bac Lieu[1]			
	Trsp	20 DAT	PI	Fl	Harv	Trsp	20 DAT	PI	Fl
Monoculture									
IR64	99	384	687	546	564	99	252	393	436
MTL119	99	390	732	640	437	99	275	420	424
Average	99	387	709	593	501	99	264	407	430
Rice–Shrimp									
IR64	99	514	396	463	364	99	95	244	—
MTL119	99	383	402	493	330	99	114	171	—
Average	99	448	399	478	347	99	104	207	—
IR64 (avg)	99	366	475	488	—				
MTL119 (avg)	99	332	496	540	—				
Diff (variety)	—	34.2	–20.6	–52.9*					
CV (%)		14.8	13.6	27.4					

Abbreviations: Trsp (transplanting), DAT(days after transplanting), PI (panicle initiation), Fl (flowering), Harv (harvest).
Diff (variety): test of difference between rice varieties across sites and systems.
* Significantly different at 5% level.
[1]Due to total crop loss there is no data at harvest stage in Bac Lieu and no data at flowering stage in rice–shrimp plots in Bac Lieu.
CV (%): coefficient of variance for 3 experiments at each site (Soc Trang or Bac Lieu).

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ACIAR Technical Reports No. 52e
(printed version published in 2003)

Leaf area index (LAI) of rice

The LAI was higher for MTL119 at 20 days after transplanting compared to IR64. In Soc Trang, the LAI of both rice varieties in the monoculture trials increased more quickly than in the rice–shrimp systems from 20 days after transplanting to harvest. In Bac Lieu, the LAI for both rice varieties in monoculture systems was similar and increased slowly after transplanting. In the rice–shrimp system in Bac Lieu, the rice plant development was poor and therefore the LAI of both rice varieties was very low. In general, the LAI of rice in Soc Trang was higher than in Bac Lieu. The trial results are outlined in Table 9.

Table 9. LAI of two rice varieties in 1998 wet season trials.

Rice variety per system	Soc Trang				Bac Lieu			
	Trsp	20 DAT	PI	Fl	Trsp	20 DAT	PI	Fl
Monoculture								
IR64	0.23	1.64	7.81	6.04	0.55	1.48	5.08	5.07
MTL119	0.25	1.44	9.87	10.22	0.74	1.49	5.64	6.19
Average	0.24	1.54	8.84	8.13	0.64	1.49	5.36	5.63
Rice–shrimp								
IR64	1.76	2.69	5.06	5.95	1.08	0.37	1.37	—
MTL119	0.77	1.89	5.27	10.12	1.44	0.46	0.89	—
Average	1.27	2.29	5.16	8.03	1.26	0.41	1.13	—
Diff (variety/sys)	0.48	0.49**	–1.14	–4.17**				
IR64 (avg)	0.87	1.81	5.57	5.76				
MTL119 (avg)	0.67	1.49	6.40	9.17				
Diff (variety)	0.20	0.32*	–0.83	–3.41				
CV (%)		31.90	21.00	21.70				

Diff (variety/sys) is a measure of interaction between rice varieties and systems across sites. A significant difference confirms that the specific values are different statistically corresponding to each difference test.
* Significantly different at 5% level.
** Significantly different at 1% level.

Dry Biomass (tonne/ha)

The biomass was higher for MTL119. The high biomass of MTL119 was one of the important factors contributing to the high yield for that species. Overall the rice biomass was higher in monoculture systems compared to rice–shrimp system. In the monoculture trials in Soc Trang, the biomass increased for both species from transplanting to flowering. In the rice–shrimp system in both districts and both species, the increase in the biomass was delayed until 20 days after transplanting due to impacts from salinity. This was also the case for the rice monoculture trials in Bac Lieu. The biomass results for rice leaf and stem are summarised in Figures 2a–d.

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ACIAR Technical Reports No. 52e
(printed version published in 2003)

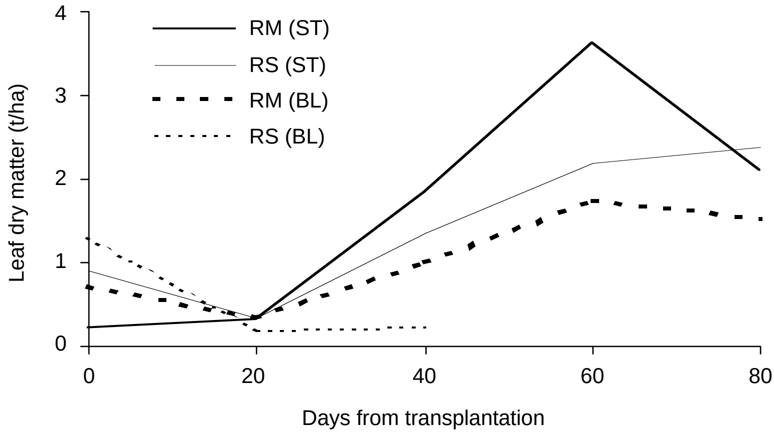

Figure 2a. MTL119: Average leaf dry matter 1998 field trials.

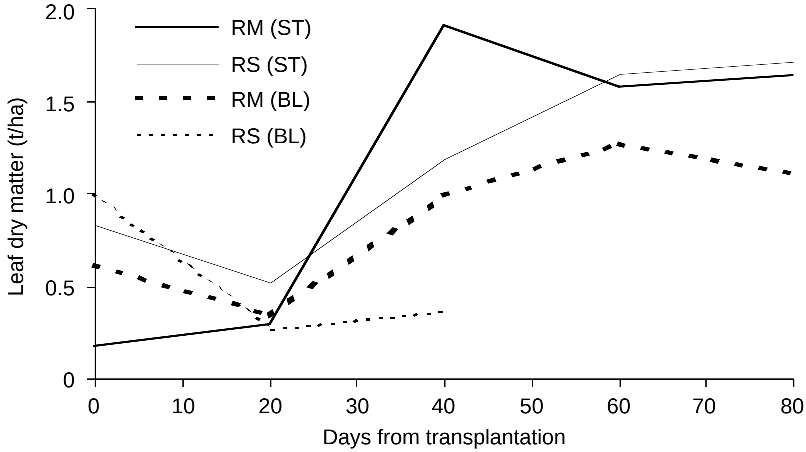

Figure 2b. IR64: Average leaf dry matter 1998 field trials.

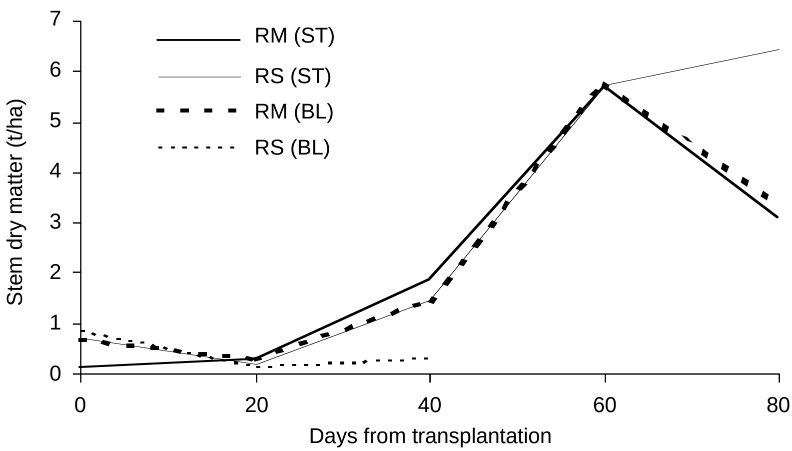

Figure 2c. MTL119: Average stem dry matter 1998 field trials.

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ACIAR Technical Reports No. 52e
(printed version published in 2003)

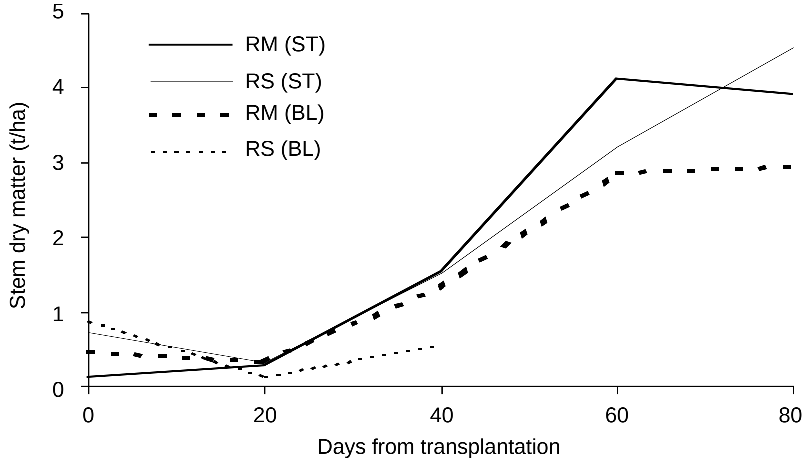

Figure 2d. IR64: Average stem dry matter 1998 field trials.

Nitrogen content

In the rice monoculture systems, the nitrogen content in the leaves and stems of the two varieties was higher compared to the rice–shrimp systems. And in Soc Trang, the level of nitrogen in leaves was higher than levels for the same system in Bac Lieu. On average the IR64 variety had higher nitrogen content in the leaf, stem and seed compared to levels for the MTL119 variety. A different capacity for nitrogen absorption between varieties is a possible explanation for these results. The nitrogen results from the 1998 field trials are outlined in Table 10.

Table 10. Nitrogen content (%) in the leaf at flowering stage and in the stem and seed at harvest, 1998 trials.

Rice variety	Soc Trang			Bac Lieu		
	Leaf	Stem	Seed	Leaf	Stem	Seed
Monoculture						
IR64	2.21	1.05	1.82	2.02	0.76	1.47
MTL119	2.03	0.95	1.53	1.66	0.66	1.33
Average	2.12	1.00	1.68	1.84	0.71	1.40
Rice–Shrimp						
IR64	2.03	0.87	1.50	Complete crop loss		
MTL119	2.09	0.79	1.54			
Average	2.06	0.83	1.52			
Diff (variety/system)	0.06 ns	0.09	0.13**			
IR64 (avg)	2.12	0.94	1.63			
MTL119 (avg)	1.83	0.82	1.49			
Diff. (Variety)	0.29**	0.12**	0.14**			
CV (%)	18.70	13.00	8.60			

** Significantly different at 1% level

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Yield and yield components

The panicle number for MTL119 was higher compared to IR64, although the difference was not statistically significant. The 1000-grain weight of MTL119 was significantly higher than IR64 and there was a significantly higher grain yield for MTL119 compared to IR64 across all trials. In Soc Trang, the yield and yield components of both varieties in the monoculture system were higher than those in the rice–shrimp system. Overall, the results from the 1998 field trials (outlined in Table 11) reaffirmed the yield advantage of MTL119 compared to IR64 observed in the 1997 field trials.

Table 11. Yield components and yield of two rice varieties between monoculture and rice–shrimp systems in 1998 wet season trials.

Rice variety /system	Soc Trang			Bac Lieu		
	Panicle /m^2	1000-grain weight (g)	Yield (t/ha)	Panicle m^2	1000-grain weight (g)	Yield (t/ha)
Monoculture						
IR64	294	26.0	2.01	308	26.5	3.81
MTL119	317	30.3	4.47	411	29.3	4.40
Average	305	28.2	3.24	360	27.9	4.11
Rice–Shrimp						
IR64	354	26.1	1.78	Complete crop loss		
MTL119	386	29.1	3.02			
Average	370	27.6	2.40			
Diff (variety/sys)	–27 ns	–3.6**	–1.84 ns			
IR64 (avg)	319	26.1	2.58			
MTL119 (avg)	349	29.8	4.00			
Diff (variety)	–30 ns	–3.7**	–1.42**			
CV (%)	26.5	3.5	20.70			

** Significant difference at the 1% level.
ns: No significant difference.

Pot experiment results: salinity tolerance of the rice varieties

Plant height

The results from pot experiments showed that the plant height of rice decreased when salinity increased. At 6% salinity, MTL119 and MTL195 were highest among the tested varieties. At 9% salinity, the plant height of all rice varieties decreased considerably, and at 12% salinity, survival was zero for all rice varieties. The results on plant height are outlined in Table 12.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 12. Plant height (cm) of rice plant under different salinity levels.

Rice variety	2 weeks after seeding (zero salinity)	2 weeks after testing (30 DAS)				
		Control (0%)	3%	6%	9%	12%
MTL119	14.5[c]	31.8[ab]	26.2	22.6[a]	11.5[a]	x
MTL167	17.2[a]	26.3[b]	23.5	18.0[ab]	x	
MTL195	16.6[ab]	32.9[ab]	25.4	19.2[ab]	7.1[ab]	
MTL205	15.1[bc]	30.4[ab]	24.9	14.2[b]	5.4[bc]	
IR64	15.3[bc]	33.2[a]	26.2	x	x	
Mean	15.7	30.9	25.2	18.5	7.3	
F-test	*	**	ns	*	*	
CV (%)	5.2	23.9				

Means followed by a common letter are not significantly different at 5% level by DMRT.
* Significant difference at the 5% level.
** Significant difference at the 1% level.
ns: No significant difference.
x: All plants died.

Root length

Roots developed in most varieties in up to 6% salinity; however, only MTL119 and MTL205 could produce roots nearly normal in 9% salinity (Table 13).

Table 13. Root length (cm) of rice plant under different salinity levels.

Rice variety	2 weeks after seeding	2 weeks after testing (30 DAS)				
		Control (0%)	3%	6%	9%	12%
MTL119	14.1[a]	14.9	15.3	15.3	15.2[a]	
MTL167	15.5[a]	13.4	11.9	11.0	x	
MTL195	14.5[a]	14.2	14.4	13.6	4.8[cd]	x
MTL205	11.3[b]	17.3	16.1	14.6	11.7[ab]	
IR64	16.9[a]	13.7	13.6	x	9.2[bc]	
Mean	14.5	14.7	14.3	13.6	10.2	
F test	*	ns	ns	ns	*	
CV(%)	10.6	35.7				

Means followed by a common letter are not significantly different at 5% level by DMRT.
* Significant difference at the 5% level.
** Significant difference at the 1% level.
x: All plants died.
ns: No significant difference.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Overall salinity tolerance

The MTL119 and MTL195 plants both grew well in salinity solution up to 6%. At 9% salinity levels, these two rice varieties also displayed the most salinity tolerance among the five varieties tested. Based on the results from the pot experiments outlined above, each of the rice varieties tested was scored according to its salinity tolerance ability. A score of 1 is the best and a score of 9 is the worst (Table 14).

Table 14. Salinity tolerance ability (score) of rice varieties.

Rice variety	Salinity (%)					Mean
	Control	3	6	9	12	
MTL119	1.0	1.0[b]	2.3[c]	6.3[b]	9.0	3.9
MTL167	1.0	3.0[a]	5.0[b]	7.0[ab]	9.0	5.0
MTL195	1.0	1.0[b]	2.3[c]	6.3[b]	9.0	3.9
MTL205	1.0	1.7[b]	5.0[b]	7.7[a]	9.0	4.9
IR64	1.0	1.0[b]	8.3[a]	7.7[a]	9.0	5.4
Mean	1.0	1.5	4.6	7.0	9.0	4.6
F-test		*	*	*		
CV (%)	12.7					

Means followed by a common letter are not significantly different at 5% level by DMRT.
* Significant difference at the 5% level.

Concluding points

Identification of suitable rice varieties

1. Under the experiment conditions, MTL119 showed the best performance. This variety displayed good growth and high yield and had the maximum tillers, panicles, grain weight, grain yield, LAI and biomass among the tested rice varieties, in both monoculture and rice–shrimp farming systems in 1997 and 1998 trials.
2. With a growth duration of 115–120 days, MTL119 is well suited to the rain-fed saline areas both in monoculture and rice–shrimp farming systems. The short duration allowed the harvesting of the crop in mid to late November, which helped to avoid damage from salinity intrusion and drought at the onset of the dry season. With the short growth duration, farmers would also have more opportunities to adjust the planting calendar in order to get better harvests of both shrimp and rice.
3. MTL119 also has good salinity tolerance qualities, which provides more secure rice production in the study area, where the start and end of the rainy season are uncertain and unpredictable.
4. Farmers commonly use IR64 and TN128; however, the relatively poor performance of these varieties in both farming systems suggests that there could be benefits gained by replacing of these varieties with MTL119.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Comparison of growth and yield of rice between the two systems

5. The growth and yield components of the rice crop in the monoculture system were always better compared to the rice–shrimp system.

6. The LAI, biomass and nitrogen content of rice in the monoculture system were also higher compared to the rice–shrimp system. The LAI of rice in the monoculture systems increased from transplanting and reached maximum values at the panicle initiation stage, while in the rice–shrimp system increases in the LAI were delayed until the flowering stage due to salinity effects. The nitrogen content in rice leaves decreased gradually from transplanting to harvesting. Nitrogen had a direct effect on growth of rice through the development of stems and leaves. Less nitrogen stored in rice leaves might be the cause of poorer development of leaves (low LAI). Low LAI at the panicle initiation stage of rice resulted in low photosynthesis and grain yields.

7. There was a relationship between rice growth and yield and the content of phosphate, potassium and sodium in the rice plant. Further research into these relationships in rain-fed saline environments is suggested.

8. Overall, based on observations throughout the experimental period, water management was found to be very important in rice–shrimp farming. Good field and land preparation was observed to be important in developing appropriate water management for ensuring successful harvest of rice and shrimp. In particular, the construction of dikes, trenches, water gates, the levelling of land and timing of water exchange between the canal and the field were observed to be very important.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 7

Salinity dynamics and its implication on cropping patterns and rice performance in rice–shrimp farming systems in My Xuyen and Gia Rai

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Abstract

The aim of this study was to quantify the temporal and spatial variability of salinity in the rice–shrimp fields in My Xuyen and Gia Rai districts. The quantification of on-farm salinity provides an essential input for assessing the potential for rice growing in the rainy season in the rice–shrimp (RS) fields along the coast of the Mekong Delta. Monitoring of the electric conductivity (EC) of the root zone soil solution, field water and water in the adjacent canals was undertaken from May 1998 to January 2000 in three rice–shrimp fields and three monoculture rice fields in each of the two districts. At both of the study sites, the wet-season desalinisation period began when the 10-day rainfall exceeded 40 mm. There was a rapid decline in EC levels in the first two months of the rainy season. In My Xuyen this was followed by a period (August to December) of reasonably constant EC values in the topsoil of 3 to 5 dS m^{-1}. In Gia Rai the EC levels in the topsoil attained a reasonably constant value of around 10 dS m^{-1} only from October to December. Salinity was found to increase sharply (salinisation period) at the recession of the rainy season. The salinity of the soil solution increased with the depth of sampling, especially in Gia Rai where the salinity increased by 10 dS m^{-1} with an increase of 10 cm in the sampling depth. Salinity also increased with distance from the field ditch. In My Xuyen, the root zone salinity in rice monoculture fields was higher than in rice–shrimp fields, while in Gia Rai, one out of three rice monoculture fields had lower EC compared to the rice–shrimp fields.

In this study the EC data collected on farms were used in combination with cumulative rainfall data to estimate time series functions of on-farm EC levels. These functions simulated on-farm EC for My Xuyen and Gia Rai sites with a high degree of confidence ($p < 0.001$). Based on the simulated long-term on-farm salinity, the rice-cropping 'window' was determined for different salinity probabilities. The cropping window in My Xuyen was wide enough to give farmers flexibility to successfully grow a rice crop in the rainy season. However, in Gia Rai the high EC levels means that rice planting may have to be delayed until September, and therefore flowering would not be possible before the onset of the salinisation phase. The findings in this study can provide a basis from which to select the most appropriate and profitable farming systems under different saline environmental conditions.

IT IS GENERALLY accepted that the dynamics of salinity in the rice–shrimp (RS) field is dependent on environmental conditions such as rainfall and salinity of the surrounding canal

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

network; however, quantitative information of these relationships is limited. The quantification of salinity dynamics and the time 'window' for rice cropping in saline-affected areas of the Delta is an important step for predicting rice performance and yield, selecting suitable rice varieties and planning cropping systems in RS systems at different localities.

In this study, temporal changes in salinity in RS and rice monoculture fields in My Xuyen and Gia Rai during the 1998 rice phase were quantified. Variations in soil salinity were explored with respect to soil depth and location in the field. The study also aimed to quantify the relationship between salinity in the RS fields and surrounding environmental factors, such as rainfall and salinity of the surrounding canal network. This study focused on understanding the implications of the findings in terms of rice cultivation, rice variety and cropping system selection.

The hypotheses in this study are:

(a) The salinity in RS fields is higher compared to rice monoculture fields during the wet season rice-growing period.

(b) There is a negative relationship between root-zone salinity and cumulative rainfall.

Materials and methods

Study sites

The study was carried out in three villages where rice–shrimp systems are widely practised: Ngoc Dong, My Xuyen District (from May 1998 to February 2000), Long Dien K, Gia Rai District (May 1998 to December 1999) and Thanh Thuong B, Gia Rai District (June 1999 to December 2000). Monitoring was conducted in three RS fields and three monoculture rice fields in both districts.

At the study sites more than 80% of the annual rainfall (average 2000 mm for Gia Rai and 1750 mm for My Xuyen) occurred in the rainy season (from May to November). According to the United States Department of Agriculture (USDA) classification, soil at the My Xuyen site is of typic tropaquepts and at Gia Rai sufic tropaquepts. More detail of the study sites is outlined in Brennan (1998) and Thanh (1998).

Monitoring salinity and water level

At each of the rice–shrimp and rice monoculture field sites, the following factors were monitored:

(a) salinity of the root-zone soil solution, ground water, field surface water and adjacent canal water in rice–shrimp and rice monoculture fields

(b) water levels in the canal, field and ground water in the RS fields.

Of the three RS fields monitored, one field (field A) was selected as the main field where the root zone salinity was monitored at four points in My Xuyen and three points in Gia Rai along a transect perpendicular to the longer sides of the field. In field A at My Xuyen, these points were at 0.2, 1.2, 3.3 and 7.7 m from the edge of the field trench. The corresponding values for field A at Gia Rai were 0.5, 1.7 and 3.7 m. In the other two RS fields (Fields B and C) and in the three rice monoculture fields (Fields D, E and F), the root zone salinity was monitored at 1.5 m from the edge of the field trench.

At each measuring point, a battery was installed of soil solution tubes at various depths (5, 15, 35, 45 cm in My Xuyen and 10, 20, 35 cm in Gia Rai). The sampling depths were at the centre of each major layer of the soil profile. The bottom end of the soil solution tubes was equipped with a 5-cm long by 2-cm diameter porous cup (air entry suction = –70 kPa) made of inert polymer. At the time of sampling (twice a week during the rainy season and once a week

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

during the dry season), the soil solution was vacuum-sucked into a glass bottle following the procedure described in Tuong et al. (1993). Water from the field surface and from the canal was collected in bottles. Hanna digital meters were used to measure the electrical conductivity (a measurement of the salinity level, EC) and the pH of the water samples. In this paper, both terms 'salinity' (in g NaCl L^{-1} or ppt) and 'electrical conductivity' (in dS m^{-1}) are used interchangeably to indicate the salinity level, with the conversion factor 1 g NaCl L^{-1} = 1.78 dS m^{-1}.

Climatic and other secondary data

Rainfall and evaporation data were collected during the study period on a daily basis at the main field of each site. Long-term climatic data for My Xuyen (1990–1999, measured 30 km from the My Xuyen site) and for Gia Rai (1988–1989 and 1992–1999, measured 40 km from the Gia Rai site) were obtained from the provincial Bureaus of Meteorology and Hydrology. Similarly, long-term data (1994–2000) on canal water salinity at Du Tho (approximately 10 km from the My Xuyen site) and Ca Mau stations were collected. At both of these stations, salinity data was also collected during May–July and November–December in 1998 and 1999, simultaneously with the data collection periods at the monitored sites in this study.

Data analysis and salinity dynamics modelling

A gamma distribution model (Thom 1968) was used to determine the probability distribution of rainfall and salinity levels using long-term rainfall and salinity data.

Since the temporal variability of salinity of the RS fields had definite phases (salinisation and desalinisation) and appeared to be highly dependent on rainfall, time series analysis was used to model the salinity dynamics (Box and Jenkins 1976). The salinity time series (EC_t) was modelled to compose a deterministic component (T_t, showing the trend of salinity change over time) and a stochastic component (Z_t, indicating the variation of salinity around the trend line) (Equation 1):

$$EC_t = T_t + Z_t \qquad (1)$$

where *t* represents the time step.

It is hypothesized that T_t is a function of cumulative rainfall at the previous time step (R_{t-1}) (Equation 2):

$$T_t = f_1(R_{t-1}) \qquad (2)$$

The cumulative rainfall was calculated from the start of the desalinisation phase. The functional form in Equation 2 (f_1) can be linear, logarithmic, power or exponential. Best-fit criterion of minimum residuals between actual (EC_{tm}) and simulated data $\Sigma(EC_{tm} - T_t)^2$ was used to evaluate the applicability of the functional form.

The stochastic component of the salinity time series (Z_t) was estimated by using auto-regressive models. The order of the auto-regressive model was selected on the basis of the goodness-of-fit and the minimum residuals between the measured and the simulated salinity $\Sigma(EC_{tm} - EC_{ts})^2$ as outlined in Box and Jenkins (1976).

The salinisation phase occurred at the end of the rainy season, at which time there was virtually no stochastic effect of rainfall distribution. The regressive models (Box and Jenkins 1976) were used to simulate the trend of salinity during this phase.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

The statistical software package SPSS was used to estimate the coefficients of the time series functions. The estimations were based on 1998 salinity and rainfall data and the functions were validated using 1999 data. The estimated functions were then used to generate 10-day salinity data for a period of 10 years (1990–1999 for My Xuyen and 1988–1989, 1992–1999 for Gia Rai).

Apart from the rainfall data, other data required to simulate long-term salinity were:

(a) the starting date of the desalinisation and salinisation phase

(b) the soil salinity at the start of the desalinisation phase.

We used the relationship between long-term dynamics of salinity and rainfall at Du Tho and Bac Lieu and at the monitoring sites to derive the starting date of the desalinisation and salinisation phases. The soil salinity values were based on the observed levels at the field sites.

Results

Experimental conditions

In Soc Trang, the rainy season starts in early April (at probability 25%) to early May (probability 75%) and ends at the end of December (probability 25%) to early December (probability of 75%). In 1998 the rainy season arrived relatively late and in 1999 it arrived relatively early. The rainy season at Bac Lieu has the same duration as in Soc Trang (at 50% probability) but rainfall at 25% and 50% probabilities in Gia Rai is higher than that in My Xuyen. The rainfall data for Soc Trang and Bac Lieu is not provided here; however, it is available in the full workshop paper.

The lower than average rainfall at the beginning of the rainy season in 1998 partly explained the higher salinity in the canal network for My Xuyen in May and early June as shown in Figure 1. In 1999, particularly heavy rainfall in the first week of April, and the subsequent heavy rainfall lowered the salinity in the canals in My Xuyen to very low levels from May to the end of the rainy season. Similarly, relatively low salinity in November and December can be attributed to the high rainfall late in the season.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

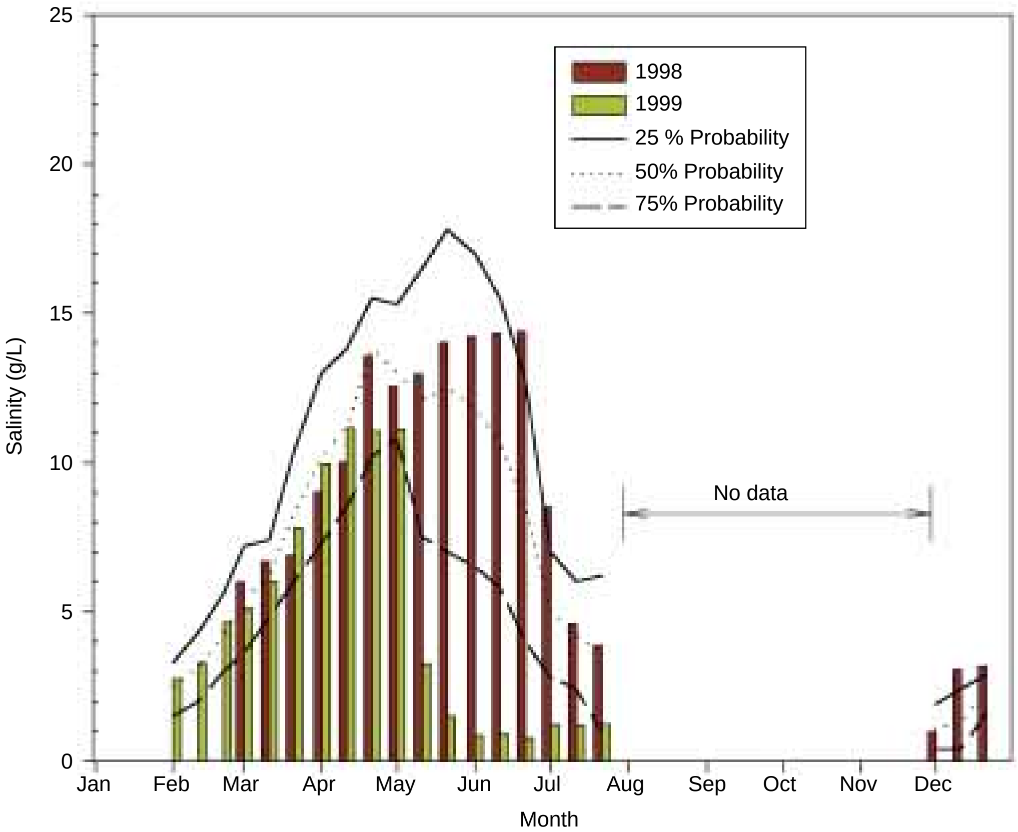

Figure 1. Canal water salinity at Du Tho station and probability of exceedence (P) = 25, 50 and 75%.

The salinity levels in Bac Lieu were found to be very high, even throughout the rainy season (Fig. 2). In 1998 the canal salinity at probability of 50% for Bac Lieu remained at about 5 g/L after 1 August. Salinity levels of less than 4 g/L were found only during September to the end of November. Salinity in 1998 exceeded the 25% probability level, corresponding to low rainfall in 1998. Salinity in 1999 was lower than the 75% probability level.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

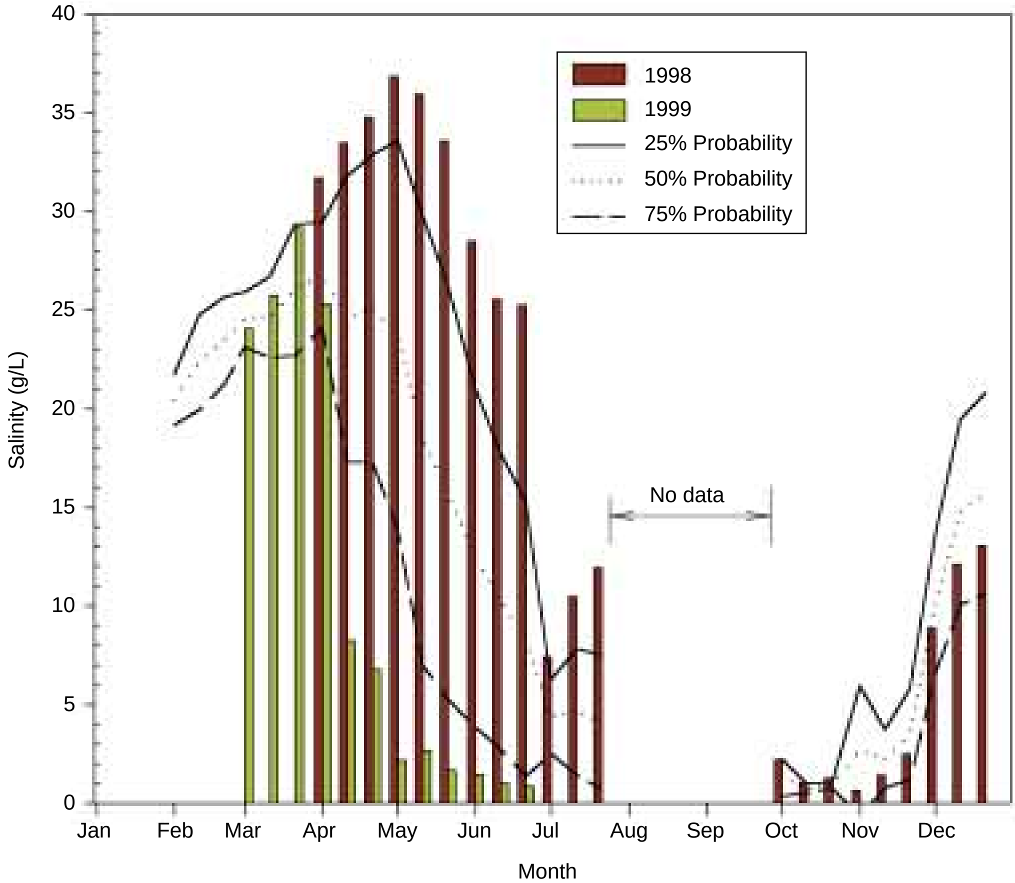

Figure 2. Canal water salinity in Ca Mau station and probability of exceedence (P) = 25, 50 and 75%[1].

[1] Data source: Bac Lieu Provincial Bureau of Meteorology and Hydrology.

Temporal variability of the monitored salinity

Figures 3 (for My Xuyen) and 4 (for Gia Rai) show the changes in EC that took place in the root-zone soil solution, the field water, and the adjacent canal water at the monitoring sites for RS fields. In My Xuyen the EC of the soil solution was measured at depths of 5, 15 and 35 centimetres. In Gia Rai the soil EC was measured at depths of 10, 20 and 35 centimetres.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

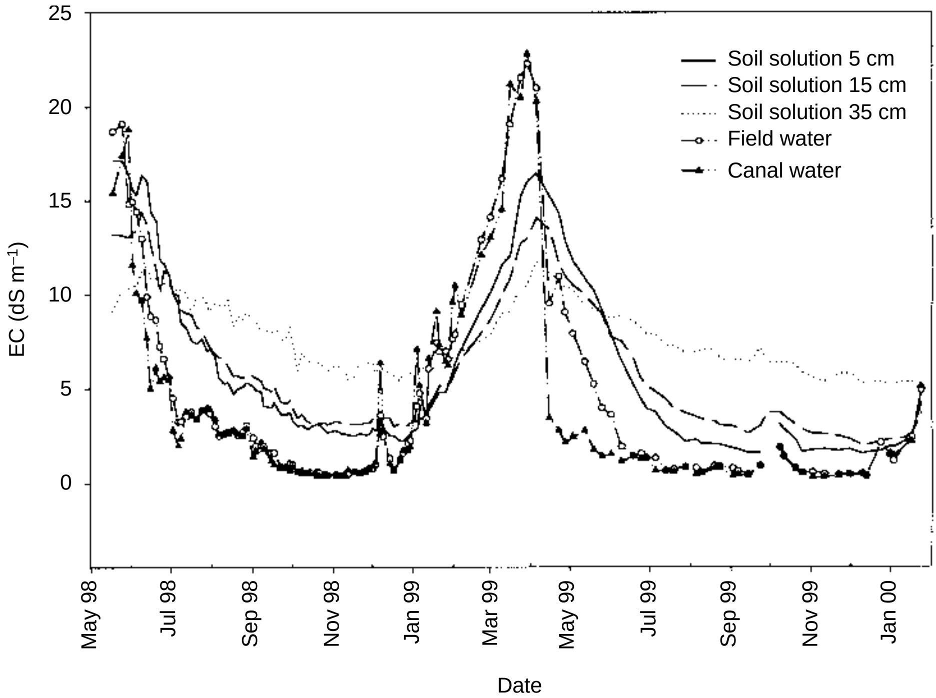

Figure 3. Soil, field water and adjacent canal water EC levels for rice–shrimp fields at the My Xuyen monitoring sites[1].

[1] The vertical and capped bars indicate the standard error of the means of 6 measurements (4 locations in 1 field and 1 in each of the other 2 fields).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

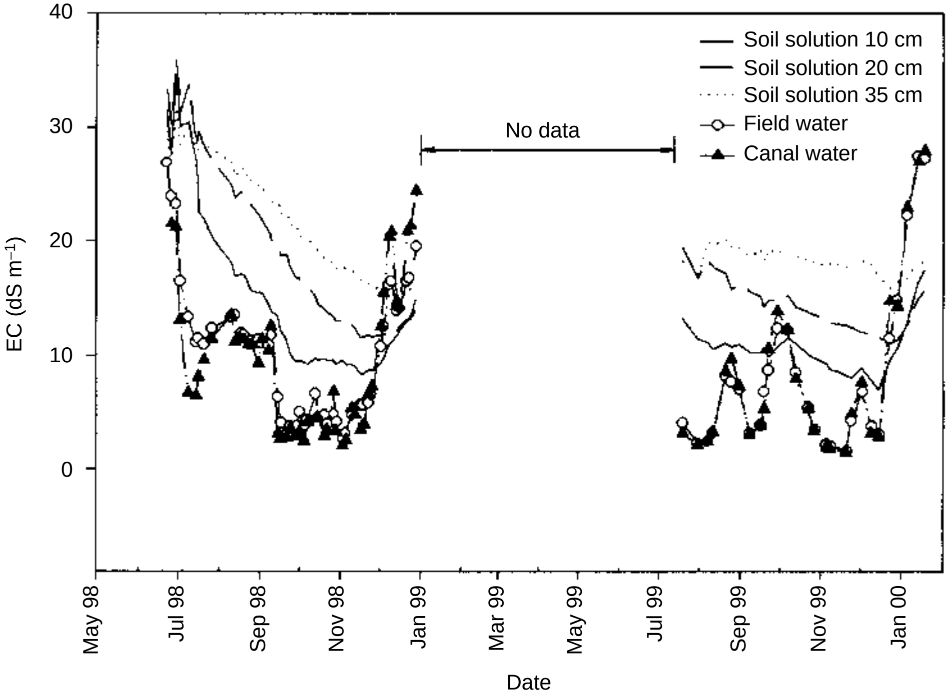


Figure 4. Soil, field water and adjacent canal water EC levels for rice–shrimp fields at the Gia Rai monitoring sites[1].

[1] The vertical and capped bars indicate SE of the means of 5 measurements (3 locations in 1 field and 1 in each of the other 2 fields).

In general there are two phases of the salinity cycle: the desalinisation phase and the salinisation phase. These phases can be seen in Figures 3 and 4.

In the desalinisation phase, salinity steadily decreases, starting from the onset of the rainy season and end at the end of the season. During the first stage of desalinisation in the study region, the EC in the canal water (CW) and field water (FW) decreased sharply from about 20 dS m^{-1} to less than 5 dS m^{-1} in My Xuyen and 30 dS m^{-1} to about 10 dS m^{-1} in Gia Rai within two months. In My Xuyen the EC of the FW remained higher than that of the CW until the beginning of June in 1998 and end of June in 1999. In Gia Rai this was the case until mid-July. The salinity in the FW further into the wet season became as low as in the EC in the CW. This is likely to have corresponded to the active flushing period when farmers used CW (in addition to rain water) to remove the salinity from the field for rice cultivation. Salinity in the root zone often started to decrease about ten days later than CW and FW. The rate of decrease in salinity levels in the root zone was also slower.

In My Xuyen, the first stage of the desalinisation phase lasted about 2.5 months. At the end of first stage in July, the EC level of the soil solution was less than 8 dS/m and it was suitable for rice transplanting or sowing. After the period of rapid decline in salinity, the salinity in most samples decreased slowly to around 2–4 dS/m at the end of the desalinisation phase in December.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

In Gia Rai, especially in the 20-cm soil layer, the rate of decline in salinity of the soil solution remained reasonably stable over the whole rainy season. Over about six months, the salinity of the soil solution declined from about 35 dS m^{-1} to about 15 dS m^{-1}. The slow decline in the root-zone salinity in Gia Rai can be attributed to the high initial soil salinity and a low saturated conductivity of the soil in Gia Rai (2.72 cmd^{-1}); it is significantly different compared to My Xuyen soil (0.26 cmd^{-1}). During the desalinisation phase, the EC of the FW was higher than that of the CW, and the latter in turn was higher than the EC of the soil solution, indicating that there was a possible removal of salinity from the soil to the field water and to the canal.

The salinisation phase started with the recession of the rain around January. This was characterised by a rapid increase (almost linearly with respect to time) in salinity at all sampling sites. Salinity of the field water was about the same as that of the canal water, suggesting that farmers actively took water from the surrounding canal for raising shrimp at the start of the dry season. Soil salinity also increased due to salinisation by the saline surface field water, and attained its maximum values again at the end of the next dry season. The average duration of the salinisation phase was similar in both My Xuyen and Gia Rai, and lasted between 3.5 and 4.5 months depending on rainfall and soil layers. This was similar in both My Xuyen and Gia Rai districts.

Salinity variation and soil depth

In general, the salinity of the soil solution during the desalinisation phase increased with depth (Figs. 3 and 4). In My Xuyen, while there was no significant difference in EC at depths of 5 and 15 cm, EC at depths of 35 cm was about 5 dS m^{-1} higher than the shallower samples. In Gia Rai, differences in EC at different layers were between 5 to 10 dS m^{-1} and were statistically significant. The variation of salinity with respect to depth was more pronounced in 1998 (low rainfall) than in 1999 (high rainfall). The lower salinity in the topsoil layers was attributed to the leaching/flushing processes which removed salinity from the top soil layers more effectively than from the deeper layers. More significant differences in salinity with respect to soil depths in Gia Rai compared to My Xuyen might be due to the different soil-saturated hydraulic conductivity of the Gia Rai soil layers.

During the salinisation phase, however, the salinity at the shallower depths increased more rapidly and became higher than that at the deeper layers around mid-February. This period corresponded to the season when farmers let the saline canal water into their fields for shrimp raising. Saline water percolated into the soil, resulting in high salinity in the topsoil layer.

Spatial variability of soil solution salinity

In My Xuyen, the results from sampling indicated that the soil solution salinity changes with the location of the sampling points in field A at My Xuyen. In general, during the desalinisation phase, the salinity was higher at points further away from the field canal. This was reversed during the salinisation phase. Similar results were found at the Gia Rai site.

The results indicated that lateral movement of water and salt to and from the field canal played an important role for both salt leaching and salinisation in the RS fields. The width of the field (or the distance between field canals) should not be too large; otherwise, salinity at the middle of the field cannot be leached adequately for rice cultivation.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Salinity in rice–shrimp and rice monoculture rice fields

The salinity increased with soil depth (as observed in RS fields) in the monoculture rice fields in both districts (Figs. 5a and b). The very large standard of errors of the means in the monoculture rice fields indicated that the variation in salinity among different fields was much larger in the monoculture rice fields than in the RS fields. The wider variation indicated that water management, or its effects, in monoculture rice fields was more diverse than in RS fields. It is likely that the salinity in RS fields was strongly affected and therefore more homogenised by the frequent exchange of water between the RS fields and the adjacent canal. Most of the monoculture rice fields were located further from the canal and did not have direct exchange of water with the surrounding canals. The salinity in the monoculture rice was more affected by factors such as the field elevation and farmer's practices of salt leaching.

In My Xuyen, salinity in RS fields was lower than in monoculture rice fields. In Gia Rai, one out of three monoculture rice fields had lower, and two fields had higher, salinity than the RS fields. Farmers took advantage of low salinity in the canal water in My Xuyen to leach out the salinity of the fields. Farmers in the monoculture rice fields did not access the canal water to leach out the salinity, which had probably been built up by capillary rise during the dry season. In Gia Rai, however, leaching using canal water could not bring down the salinity of the soil to a lower level because:

(a) the initial salinity of the soil at the end of the dry season was very high (30 to 40 dS m^{-1})
(b) the salinity of the water during the rainy season remained high (more than 5 dS m^{-1})
(c) the soil has low hydraulic conductivity.

If rice monoculture farmers could prevent the saline water intrusion into their fields during the dry and the rainy seasons, the salinity could be lower than in the RS fields.

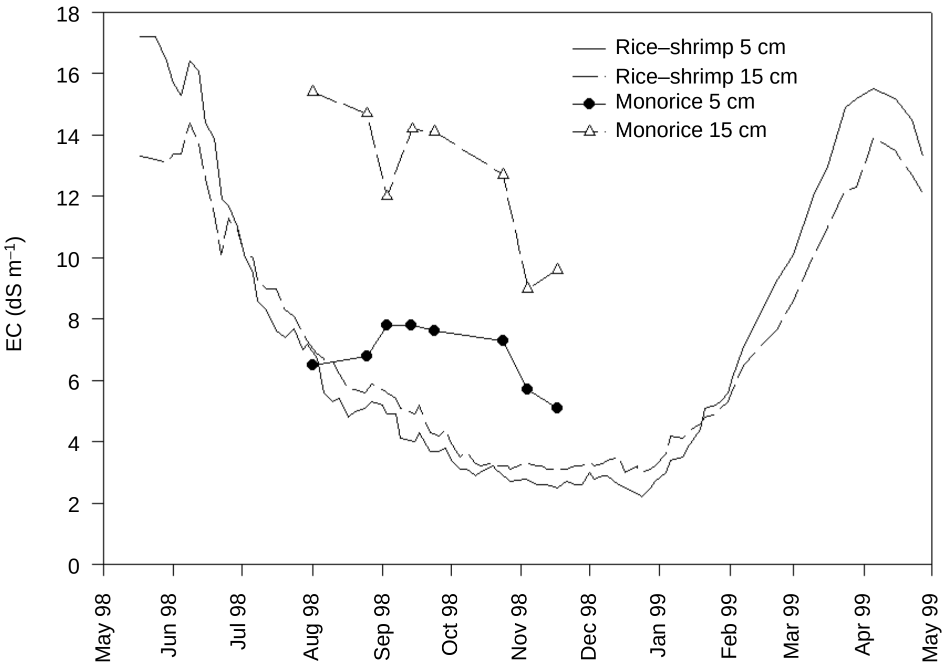
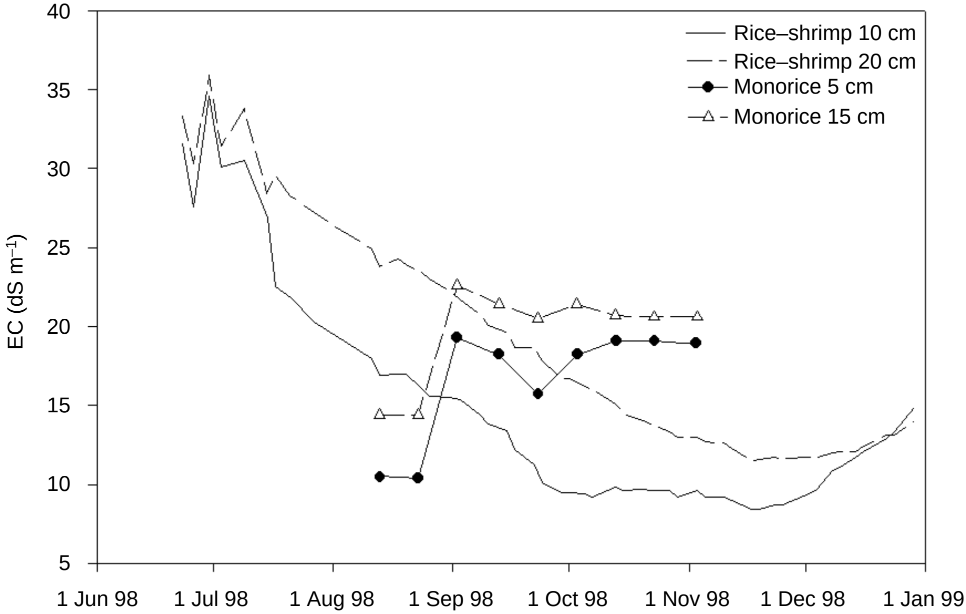


Figure 5a. Soil salinity in rice monoculture and rice–shrimp fields, My Xuyen.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)



Figures 5b. Soil salinity in rice monoculture and rice–shrimp fields, Gia Rai.

Estimating long-term salinity at the study sites

In this section, the estimated time series models of salinity (relating on-farm salinity and rainfall) are presented. These models were used to generate long-term salinity data at the study sites.

In Table 1a and 1b the estimated time-series functions for My Xuyen 0–5-cm soil layer salinity are presented. These are a selection of deterministic and stochastic functions. Results in Table 1a indicate that the exponential and logarithmic functions are able to simulate EC values better than the power or linear functions. This is indicated by the smaller residues ($\Sigma(EC_{t1998} - T_t)$) between the observed values (in 1998) and the computed salinities from the exponential and logarithmic functions, compared to the power or linear functions.

In Table 1b the results from an estimation of the stochastic component of the EC levels is shown. Two functional forms were compared: first order auto-regressive function AR(1) and the second order AR(2). Results show that both of these functions satisfied the Aikaike Information Criterion, randomness and normality tests (Box and Jenkins 1970). The estimation using the AR(1) function required data on the salinity and cumulative rainfall of the previous time step ($t - 1$), and the AR(2) function required data of the two previous time steps ($t - 1$ and $t - 2$). Therefore the AR(1) was selected because it required less data input.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 1. Estimation of soil salinity for 0 –5 cm soil layer in My Xuyen, using alternative functional forms.

(a) Deterministic component $T_t = f(R_{t-1})$

Type	Equation T_t	$\Sigma (EC_{1998} - T_t)^2$	R^2
Exponent	$15.782\ e^{-0.001R_{t-1}}$	24.6	0.96^{**}
Power	$696.55\ R_{t-1}^{-0.730}$	162.46	0.92^{**}
Linear	$-0.00647R_{t-1} + 13.77$	76.28	0.84^{**}
Logarithmic	$-5.14 \ln(R_{t-1}) + 41.16$	18.73	0.96^{**}

(b) Stochastic component $Z_t = f(Z_{t-1},..) + \varepsilon_t$ (1)

	Test of AR coefficients			Test of white noise ε_t		
AR function	$\varnothing_I$	Goodness of fit AIC (2)	Adequate order of AR Prob (t)	Residual variance σ_ε^2	Randomness χ computed (3)	Normality $\gamma_{computed}$ (4)
AR(1) $Z_t = \varnothing_1 Z_{t-1} + \sigma_\varepsilon^2 .\xi_t$	0.784	42.2	0.00^{**}	0.36	6.05	Yes
AR(2) $Z_t = \varnothing_1 Z_{t-1} + \varnothing_2 Z_{t-2} + \sigma_\varepsilon^2 .\xi_t$	1.113 –0.345	41.7	0.00^{**} 0.11^{ns}	0.34	3.02	Yes

All computations, criteria are according to Box and Jenkins (1970).
(1) ε_t is white noise ~ $N(0, \sigma_\varepsilon^2)$, $\varepsilon_t = \sigma_\varepsilon^2 .\xi_t$, $\xi_t \sim N(0, 1)$; $\varnothing_i$ determined using the Maximum Likelihood method.
(2) AIC = Aikaike Information Criterion.
(3) Randomness test of ε_t, using Port Manteau method. Randomness is accepted if $\chi_{\text{computed}} < (\chi_{0.95,df=6}) = 12.6$).
(4) Normality test of ε_t:, accepted if skewness $\gamma_{computed} < (\gamma_{0.05,\ 21}=1.061)$.
** Significant at 0.01 probability.
ns: Not significant.

Rainfall and salinity data in 1998 were used to calibrate the estimated time series function of salinity in the 0–5 cm soil layer for My Xuyen during the desalinisation phase. Among the above functional forms in Table 1, the exponent form of the deterministic component provides a simple and clear indication of the negative relationship between EC and cumulative rainfall (Equation 3). Moreover, the high significance (**) and high R^2 (0.96) of the exponent functional form shows a best fit of this form to the measured data.

$$EC_t = 15.782\ e^{-0.001R_{t-1}} + 0.784\ (EC_{t-1} - 15.782\ e^{-0.001R_{t-2}}) \quad (3)$$

In the above equation, *t* was measured in 10-day periods from the date that salinity started to decline. In Figure 6 the estimated function (Equation 3) is compared against the measured data. The vertical and capped bars indicate the standard error of the means from four locations in the field. The 1999 data were used to validate the estimated equation. Subscripts *t* designate 10-day

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

periods from the date that salinity starts to decline and *R* is the cumulative rainfall from the date that salinity starts to decline.

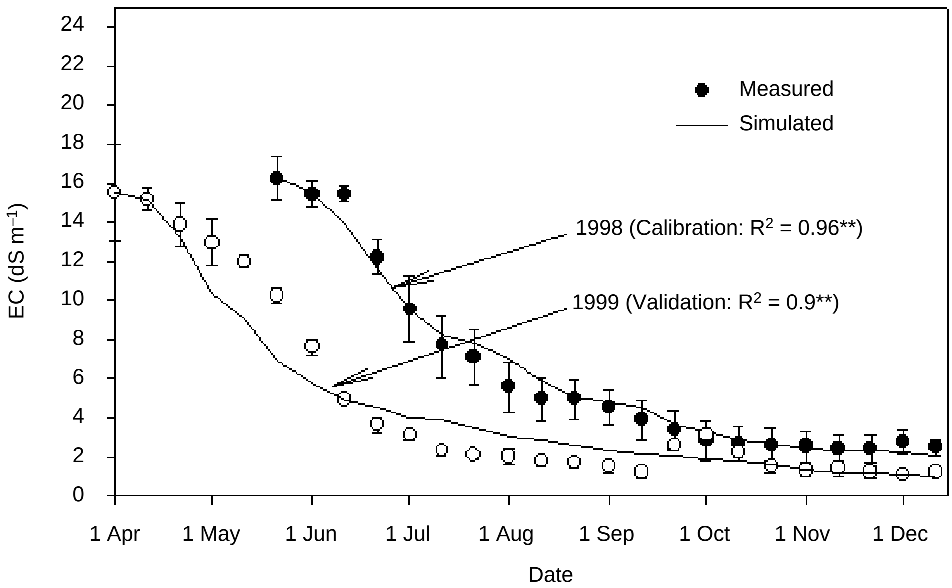


Figure 6. Estimated and observed soil solution salinity at 5 cm depth for the rice–shrimp system: desalinisation phase, My Xuyen.

Similarly for the salinisation phase, salinity 'data' in 1999 were used to calibrate the estimated regressive model of salinity in the 0.5 cm layer at My Xuyen (with high R^2 of 0.995; $p<0.01$). Data in 2000 were used for validation (with high R^2 of 0.88; $p<0.01$).

Figure 7 shows that the estimated regressive model (Equation 4) simulates salinity very well. The vertical and capped bars in Figure 7 indicate the standard error of the means from four field locations.

$$EC_t = EC_0 + 0.701t^{1.288} \quad (4)$$

where:

EC_0 is the EC value at the beginning of the salinisation period.

t designates 10-day periods from the date that salinity starts to increase.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

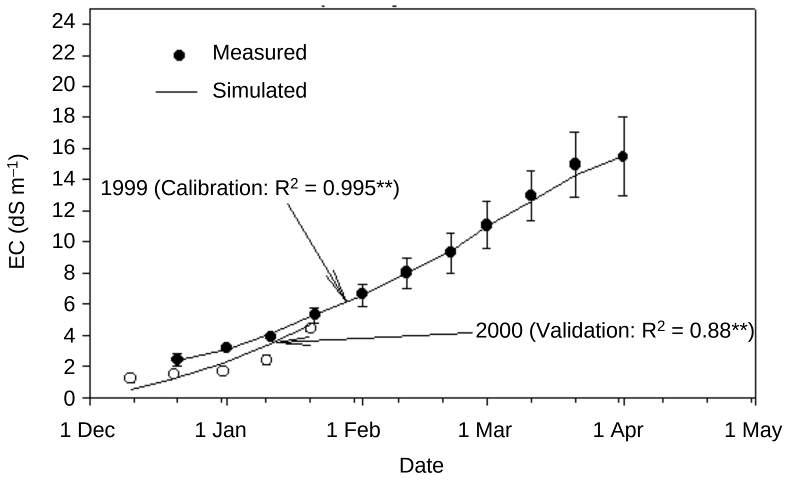


Figure 7. Estimated and observed soil solution salinity at 5 cm depth for the rice–shrimp system: salinisation phase, My Xuyen.

In Table 2 the selected functions for computing salinity at different soil layers at My Xuyen and Gia Rai are listed with their respective coefficient of determinants.

Table 2. Estimated time series functions for predicting on-farm salinity in My Xuyen and Gia Rai.

		R^2			R^2	
	Desalinisation phase	**1998**	**1999**	**Salinisation phase**	**1999**	**2000**
My Xuyen						
0–5 cm	$EC_t = 15.782\ e^{-0.001Rt-1} + 0.784(EC_{t-1} - 15.782\ e^{-0.001Rt-2})$	0.96**	0.90**	$EC_t = EC_0 + 0.701\ t^{1.288}$	0.995**	0.88*
5–15 cm	$EC_t = 13.885\ e^{-0.0007Rt-1} + 0.745(EC_{t-1} - 13.885\ e^{-0.0007Rt-2})$	0.98**	0.94**	$EC_t = EC_0 + 0.273\ t^{1.564}$	0.998**	0.89*
Field water	$EC_t = 12.566\ e^{-0.0015Rt-1} + 0.682(EC_{t-1} - 12.566\ e^{-0.001Rt-2})$	0.97**	0.85**	$EC_t = EC_0 + 0.879\ t^{1.376}$	0.96**	0.86*
Gia rai						
0–10 cm	$EC_t = 31.16e^{-0.0008Rt-1} + 0.341(EC_{t-1} - 31.16e^{-0.0008Rt-2})$	0.97**		$EC_t = EC_0 + 1.647t - 0.045$	0.99**	
10–20 cm	$EC_t = 28.682e^{-0.001Rt-1} + 0.378(EC_{t-1} - 28.682e^{-0.001Rt-2})$	0.93**		$EC_t = EC_0 + 0.956t - 0.48$	0.93*	

Sensitivity analysis was conducted on the initial salinity level for the desalinisation period. The results indicated that the effect of a variation of plus or minus 3 dS m^{-1} in the initial soil salinity (at the start of the desalinisation) on the computed salinity damped out quickly and its

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

effect became negligible after four ten-day periods of computation (i.e. before the start of the rice crop). The effects of the initial soil salinity on the computed salinity dynamics can thus be neglected in the consideration of time windows for rice cultivation.

Simulated long-term salinity at the study sites

The functions in Table 2 were used to simulate 10-day salinity of different soil layers and of the field water at the two sites for 1990–1999 in My Xuyen, and 1988–1989, 1992–1999 in Gia Rai. For each year, the start of the desalinisation period was the 10-day period at the beginning of the rainy season with rainfall greater than 40 mm, and the beginning of the salinisation period was the 10-day period at the end of the rainy season with rainfall less than 40 mm. The initial soil solution salinities (at the start of desalinisation) in the two topsoil layers at My Xuyen (16, 14 dS/m) and Gia Rai (31.8, 31.7 dS/m) were derived from the 1998 and 1999 measured values.

Figures 8a and 8b shows the variation of the computed salinity of the soil solution at 5 and 15 cm depths in My Xuyen for different probabilities of exceedence. In nine out of ten years (at 90% probability) the soil solution salinity started to decline in May. But in years with late rainfall, which may occur once in 10 years (10% probability), the salinity only started to decline in June. Soil solution salinity started to increase as early as November (10% probability), but in most of the years, salinity increased from December.

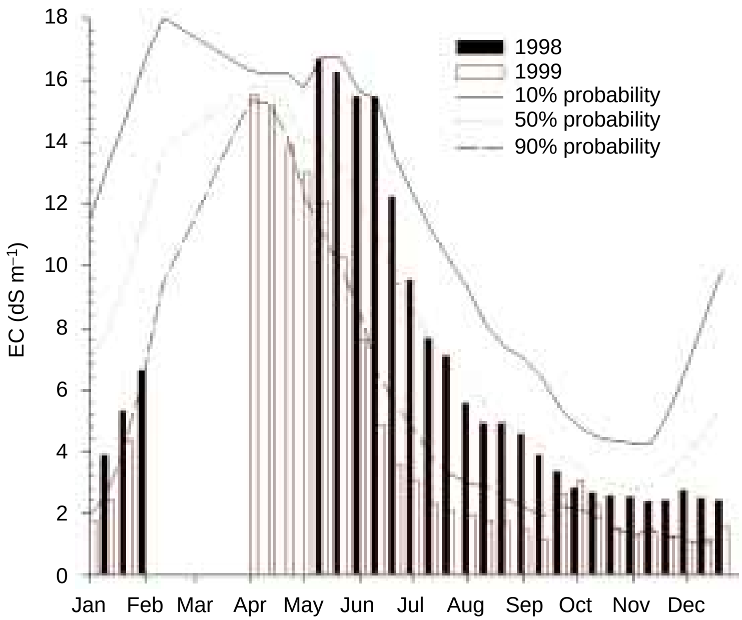


Figure 8a. Simulated soil solution salinity for 1998 and 1999 for the 5 cm depth in My Xuyen. Probabilities of exceedence are included.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

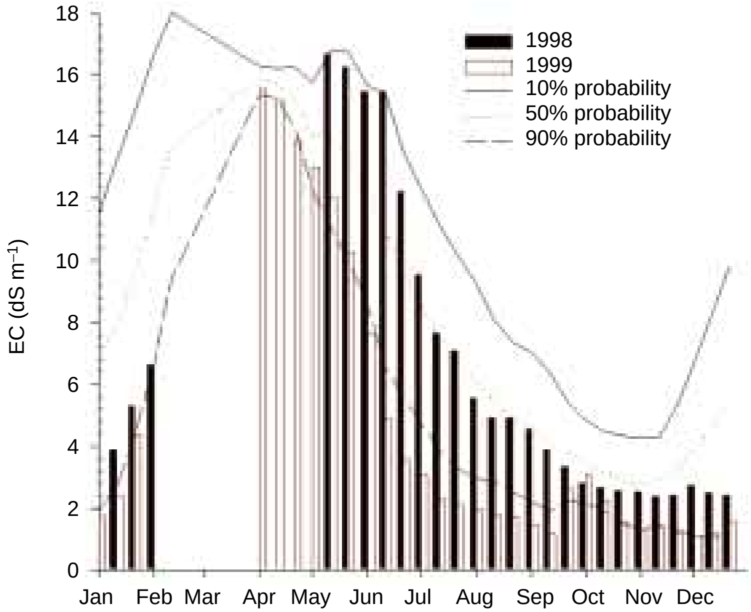


Figure 8b. Simulated soil solution salinity for 1998 and 1999 for the 15 cm depth in My Xuyen. Probabilities of exceedence are included.

For most of the probabilities, the computed soil solution salinities in Gia Rai (Fig. 9a,b) started to decline in April/May, which was earlier than at My Xuyen. The salinisation period in Gia Rai began at about the same time as in My Xuyen (in November).

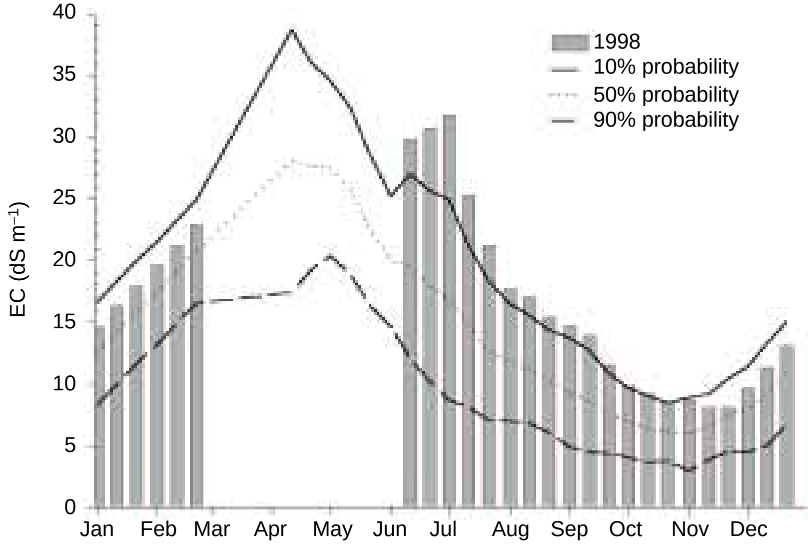


Figure 9a. Simulated soil solution salinity for 1998 for the 10 cm depth in Gia Rai. Probabilities of exceedence are included.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

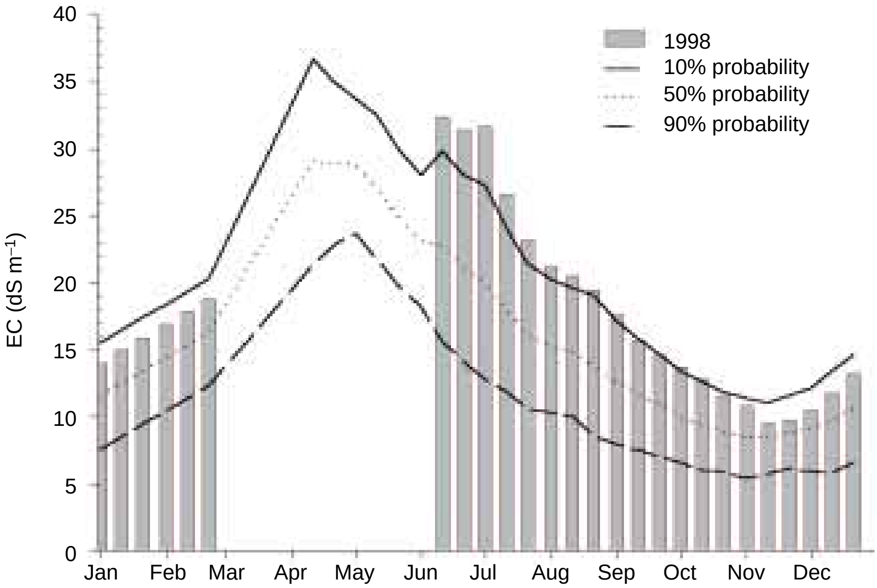


Figure 9b. Simulated soil solution salinity for 1998 for the 20 cm depth in Gia Rai. Probabilities of exceedence is included.

Implications of salinity dynamics on cropping patterns and rice performance in rice–shrimp system

The effect of salinity on rice performance depends on rice variety, planting method, seedling age, duration of exposure to salt, salinity level and weather (IRRI 1975). Rice is very sensitive to salinity at seedling stage (Yeo et al. 1991) and therefore it is important to determine the possible transplanting dates to assure seedling survival. Salinity levels of EC 5–6 dS m^{-1} imposed at seedling stage can cause a significant decrease in plant height, root length, the emergence of new roots and dry matter (Akbar and Yabuno 1974). The results by Castillo et al. (1999) indicated however that the rice plant could recover from salinity stress imposed at the seedling stage if the salinity exposure was not prolonged. Castillo found that salinity of 12 dS m^{-1} imposed at transplanting for 15 days only reduced rice yield by about 10%. A conservative threshold salinity level then for rice transplanting is around 10 dS m^{-1}.

In My Xuyen, at probability of 50%, the salinity in the topsoil layer reaches 10 dS m^{-1} at the end of May (Fig. 8a). This means that, on average, in My Xuyen rice can be transplanted as early as the end of May. However, in years with low rainfall (probabilities 10% and 20%), transplanting should be delayed until the end of July when salinity levels fall below 10 dS m^{-1}. In practice, most farmers transplanted later (in August) because they wanted to prolong the harvest of their shrimp. In Gia Rai, on average, rice can be transplanted in August, but in years with low rainfall, the date of transplanting should be delayed until late September (Fig. 9a).

Rice yield is very susceptible to salinity during the reproductive stage, especially at the panicle initiation and flowering stage (Khatun and Flowers, 1995). Castillo et al. (1999) showed that salinity levels of EC of 12 dS m^{-1} applied for 15 days at PI or at flowering led to a reduction in

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

the grain yield by about 40–60%. Prolonged salinity stress during the reproduction stage of the crop may also cause further reductions in yield. To maintain rice yields at about 50% of the yield in non-saline conditions, rice plants should reach flowering before the soil solution salinity of the topsoil reaches 10 dS m^{-1}. In My Xuyen at probability of 50%, this salinity level corresponds to about the middle of January. In years with early recession of rainfall, rice should be in the flowering stage by mid-December to avoid significant salinity damage. In Gia Rai, in an average year, rice should reach the flowering stage by about mid-December, and in years with high salinity, results show that rice should flower before the middle of November to avoid heavy losses.

The results indicate that My Xuyen has a wide 'cropping window' for rice cultivation. Rice yield is, however, reduced compared with the salinity-free condition. The degree of reduction will vary with the date of transplanting. It is important to determine which cropping calendar will produce the highest combined income from rice and shrimp. The 'window' for rice cultivation in Gia Rai is much smaller. In high salinity years (probability 10–20%), the possible duration from transplanting to flowering is only about one month (middle of September to middle of November) and therefore selection of very short duration varieties is necessary. Furthermore, the salinity of the root zone is likely to be higher than 6 dS/m anytime (Fig. 9a and 9b), which means that even if rice plants survive after transplantation, heavy yield loss would occur due to prolonged salinity stress.

Concluding comments

It was observed that salinity in the canal systems surrounding the rice–shrimp fields declined sharply when 10-day rainfall exceeded 40 mm. Daily exchange of field water with canal water at the beginning of the rainy season was found to help expedite the leaching and flushing of the salinity from the root zone of the rice–shrimp field, which may help to advance the date of planting. This water management meant that the salinity in rice–shrimp fields was not higher than the levels in monoculture fields.

This study illustrated the usefulness of time series models and regressive analyses in generating long-term salinity data from the rainfall. It is important to note, however, that these models are valid only for the same management and at the same sites as in the study. There is significant scope to use the model to explore the salinity effects of other management factors, such as minimising the exchange between field and canal water.

The study identified the time window for growing rice at the two sites, but it did not give quantitative data on rice yields and how yields may change under various management scenarios, such as the planting date, within the time window. Other detailed crop growth models, such as ORYZA (Kropff et al. 1994; Wopereis et al. 1996) are needed to help answer these questions. In Tuong et al. (this Report) further analysis is conducted using ORYZA where rice yields are simulated under different planting dates. This analysis can provide greater accuracy in identifying suitable time window in order to achieve high rice yields.

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Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 8

Phenological and physiological responses of a rice cultivar to level and timing of salinity stress

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Abstract

Process-based understanding of the response of rice to salinity stress is crucial for being able to assess rice performance in saline conditions and also for developing models that can simulate rice development when it is subjected to salinity. In this paper results are presented from two greenhouse experiments in Vietnam and one experiment in the phytroton at IRRI that were conducted to quantify the response of rice cv. IR64 to salinity. In the experiments, the rice plants were subjected to salinity levels varying from EC 4 to 18 dS m^{-1} for 14 days at three growth stages (transplanting (TP), panicle initiation (PI) and flowering (FL)). The results showed that salinity stress at TP and PI delayed the flowering and maturity date of rice. A positive relationship was found between the delay of the flowering and maturity date (from five to ten days) and salinity levels. Salinity stress at FL increased leaf senescence and reduced the grain-filling period, especially at salinity stress level 18 dS m^{-1}. Treatments with EC 6 dS m^{-1}, and EC 12 dS m^{-1} imposed at TP, did not reduce grain yields significantly compared to the control treatment. Most seedlings died after three to eight days of imposition of salinity levels of EC 18 dS m^{-1} at transplanting. However, if stress was relieved before death of seedlings, they recovered and resulted in about 20% yield reduction. Salinity of EC 12 and 18 dS m^{-1} imposed at PI reduced the number of spikelets, created sink limitation during the grain-filling period and yielded only 80% (for 12 dS m^{-1}) and 35% (18 dS m^{-1}) of the yield of the control treatment. Salinity of EC 12 and 18 dS m^{-1} imposed at FL reduced 1000-grain weight and produced about 40% and 80% of yield of the control treatment. These findings support our hypothesis that rice responses to short-term salinity stress are similar to drought-stress responses.

SEVERAL STUDIES HAVE been conducted to investigate the effects of salinity on rice crops (Pearson et al. 1966; Akbar and Yabuno 1974; Flowers and Yeo 1981; Aslam 1987; Alamgir et al. 1989; Dubey and Sharma 1989; Azam 1992; Khatun and Flowers 1994a,b; Katun et al. 1995). In some experiments, low salinity at the early growth phase has been found to stimulate plant growth; however, all studies have found that high salinity levels at all growth phases inhibit the growth and yield of rice.

The impacts from salinity have been shown to vary at different growth phases. For example, the rice grain yield tends to be more sensitive to salinity at the later stages of vegetative growth, although very young seedlings are also particularly sensitive to salinity stress. However, research to understand the effects of salinity at various crop growth stages and the varying effects for different timing of salinity stress is very limited. Such research is important to enable the

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

development of crop growth models to understand, simulate and predict the response of rice to salinity stress.

The aim of this study was to quantify the interactive effects of salinity level and timing on rice-growth and yield. A series of experiments were conducted to evaluate the interaction of salinity levels and timing of application, and to quantify the effects of salinity on phenology, biomass accumulation, yield and yield parameters for IR64, as a basis for developing a model assessing rice response to salinity. It was hypothesised that the responses of rice plants to short-term salinity stress are similar to drought-stress responses.

Materials and Methods

Experiment set-up

Rice response to salinity was tested in the following three experiments:

Experiment 1: Greenhouse experiments at the University of Agriculture and Forestry, Ho Chi Minh City (UAF) — November 1998 to February 1999

Experiment 2: Greenhouse experiments at UAF — May to August 1999

Experiment 3: Controlled environment experiments in a phytotron facility at the International Rice Research Institute — March to June 1999.

In each experiment, the interaction of salinity levels and timing of salinity application was evaluated in a split-plot design experiment with four replications.

The main plots were three salinity (C) levels: 4, 8 and 12 dS m^{-1} (Experiment 1), and 6, 12 and 18 dS m^{-1} (Experiments 2 and 3). The sub-plots were three salinity application timings (T) at different crop growth stages of transplanting (four days after transplantation in experiment 1 and 2, and one day after transplanting for experiment 3), panicle initiation and flowering.

At each application time, the stress imposition lasted for 15 days or until leaf-rolling score 5 was reached. This degree of leaf rolling was scored by visual observation of the leaf cross-sectional curvature following the method describe in O'Toole et al. 1979. Score 5 is attained when the leaf is completely rolled. Apart from the nine stressed treatments, one control treatment was included where plants were grown in optimal conditions throughout the crop season.

Materials and culture management

Soils and planting material

Pre-germinated rice cv. IR64 seeds were grown in seedling trays at one seedling per 1 cm^3 section of the tray filled with soil. Fourteen-day-old seedlings were transplanted into 25-cm height × 20-cm diameter PVC pots, which contained about 8.5 kg of 0.5–1-mm sand, one seedling per pot, with the soil intact during transplanting. One hole was cored at the bottom of each pot for drainage and leaching purposes. The holes were covered with a fine screen cloth to avoid loss of sand particles during the frequent drainage and leaching processes.

Nutrient solutions

Macro and micro-nutrients were supplied to the pots by nutrient solutions prepared according to the procedure described by Yoshida et al. (1996). Nutrient solution was maintained at 3 cm above sand surface, by adding de-mineralised water. Daily monitoring of the pH of the nutrient solution was conducted and maintained using 1N hydrochloric acid (HCl) or 1N sodium hydroxide (NaOH) so that the pH did not deviate from the level of 5.5, which is critical in order to maintain

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

the balance of available nutrients. The nutrient solution was changed every week during the vegetative stage of the crop up to flowering and thereafter every four days up to full maturity.

Salinity imposition

The experiment salinity levels were prepared by adding table salt (NaCl) to the nutrient solution until it reached the specified EC value. For example, approximately 4.5g NaCl was added to 1 L of the nutrient solution to give an EC of 8 dS m^{-1}. After adjusting the desired salinity, the pH of the entire culture solution was again adjusted to 5.5 before being added to the respective pots.

At the start of the stress period, the nutrient solution was drained off the pot to be replaced by the specified salinised nutrient solution. EC values were measured at the surface water, in the middle of the pot (approx. 5–8 cm from the surface) and at the bottom (approx. 15–18 cm from surface). If the specified EC was not attained, soil solution in the pot was again drained and replaced by salinised solution. This process was repeated until the desired EC was recorded throughout the depth of the sand layer.

To maintain the desired level of nutrient, the soil solution in the stressed pot was also changed at the same frequency as those not undergoing stress. In the experiments, salinity stress was stopped when the first sign of senescence was observed. This was done until the plant reached maturity to investigate the effect of stress during the recovery. After the completion of the stress period, the stressed pots were drained and soil solution was replaced by the normal nutrient solution. This process of leaching was repeated several times until the EC of the soil solution in the (previously stressed) pots was similar to the EC of water used in preparing nutrient solution.

Plant sampling and yield parameters

We recorded the date of PI, FL and physiological maturity (PM) of all treatments. Sequential plant samplings were taken at transplanting, active tillering, PI, FL, grain filling (GF) and at PM, for biomass and its partitioning (leaves, culm and panicle), tiller number and leaf area determination. At each salinity application, plants were sampled at 7 and 14 days after imposition of salinity. Leaf length and number, tiller number and plant height were measured twice a week in non-stressed plants and daily in stressed plants.

At PM, straw yield and grain yield and yield components were determined per pot. Grain yield was adjusted to 14% moisture. The total straw weight and partitioned parts were determined for constant oven drying at 70°C. Roots were also taken from each pot, washed and cleaned, and the total dry weight was recorded.

Results

Crop mortality

At the salinity level of 18 dS m^{-1} imposed at the transplanting stage, the rice plants attained leaf scores of 5 and senescence was observed after three days in experiment 2 and seven days in experiment 3. Prolonged salinity stress after the initial stress at the time of transplanting resulted in further crop mortality. Stress imposed at PI and FL did not result in mortality.

Phenology

A delayed flowering and maturity, compared with the control, was observed in all treatments for all salinity levels imposed at TP and PI (Table 1). The application of salinity stress at TP delayed flowering and PM on average by five days for 6 dS m^{-1} and seven to ten days for both 12 and 18 dS m^{-1} treatments.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Application of salinity at PI delayed flowering and the maturity of the main culm by two to five days. Plants stressed at PI were characterised by the new nodal shoots (discussed below), which remained green when the normal panicles already had reached the maturity stage. We opted to harvest the PI-stressed plants at five to twelve days later than the control treatment.

Application of salinity stress at FL delayed physiological maturity for five days in six and 12 dS m^{-1} treatments. Salinity of 18 dS m^{-1} applied at flowering advanced the physiological maturity for two days compared with the control in experiment 3, but in experiment 2 this stress delayed the maturity by three days.

Table 1. Salinity effects on phenological development dates of the main tiller under different salinity stress levels and timings.

Treatment	Stress period		PI	90% flowering		Maturity	
	Start	End	Date	Date	SE (days)	Date	SE (days)
Experiment 2							
C0	n/a	n/a	5 Jun	21 Jun	—	17 Jul	—
C6-TP	12 May	26 May	5 Jun	24 Jun	—	20 Jul	—
C12-TP	12 May	26 May	10 Jun	24 Jun	—	23 Jul	—
C18-TP	12 May	14 May	10 Jun	27 Jun	—	26 Jul	—
C6-PI	5 Jun	19 Jun	5 Jun	20 Jun	—	18 Jul	—
C12-PI	5 Jun	19 Jun	5 Jun	20 Jun	—	18 Jul	—
C18-PI	5 Jun	12 Jun	5 Jun	22 Jun	—	20 Jul	—
C6-FL	21 Jun	5 Jul	5 Jun	21 Jun	—	17 Jul	—
C12-FL	21 Jun	1 Jul	5 Jun	21 Jun	—	17 Jul	—
C18-FL	21 Jun	24 Jun	5 Jun	21 Jun	—	20 Jul	—
Experiment 3							
C0	n/a	n/a	25 Apr	12 May	*	16 Jun	1
C6-TP	12 Mar	26 Mar	29 Apr	16 May	*	21 Jun	2
C12-TP	12 Mar	26 Mar	4 Apr	18 May	1	22 Jun	2
C18-TP	12 Mar	19 Mar	4 Apr	20 May	*	19 Jun	2
C6-PI	3 May	17 May	29 Apr	13 May	1	17 Jun	2
C12-PI	3 May	17 May	29 Apr	14 May	*	18 Jun	*
C18-PI	3 May	17 May	29 Apr	16 May	1	20 Jun	1
C6-FL	17 May	31 May	29 Apr	12 May	1	17 Jun	2
C12-FL	17 May	31 May	29 Apr	12 May	1	17 Jun	1
C18-FL	17 May	31 May	29 Apr	12 May	1	13 Jun	2

n/a: Not applicable
— No data
* Less than 1

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Tiller number

Stresses from 4 to 8 dS m^{-1} at transplanting did not affect the numbers of tillers, but the 12 and 18 dS m^{-1} treatments significantly reduced the tiller numbers compared to the control treatment. All salinity levels imposed at PI resulted in a decline in tiller number during the stress imposition period; the decline was more severe for EC 18 dS m^{-1} (Fig. 1, for experiment 3). After the relief of the salinity stress, the 4–12 dS m^{-1} salinity treatments maintained their lower tiller numbers. In the 18 dS m^{-1} treatment, however, a high number of nodal tillers were formed after the relief of the stress, resulting in increased tiller numbers until 80 DAT, when the tiller numbers declined at maturity. At maturity, all salinity levels had a similar tiller number.

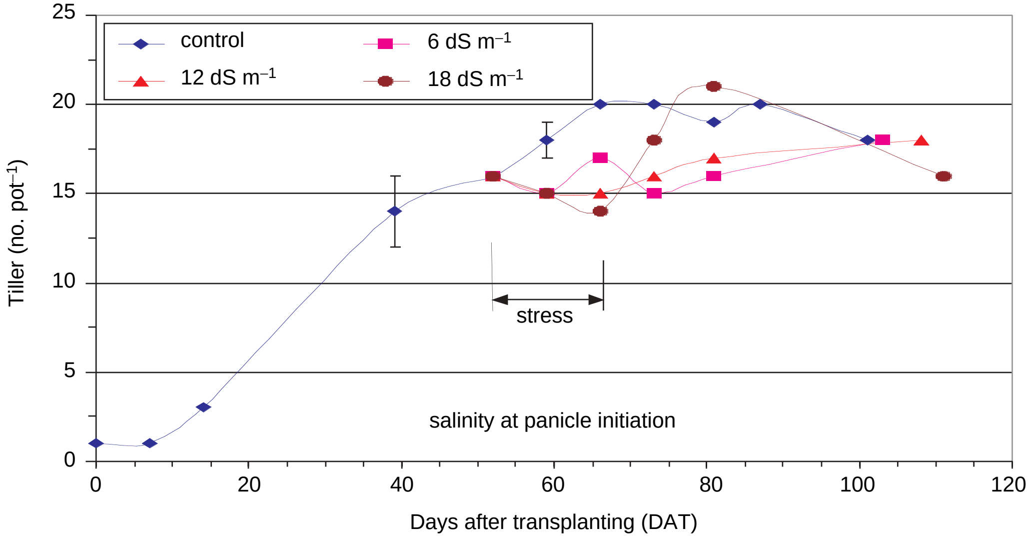

Figure 1. Affects of salinity stress imposed at PI on the number of tillers (IR64).

Salinity stress at flowering reduced the number of tillers for all salinity levels. The higher the stress level, the greater was the reduction. At maturity, the tiller number in the 18 dS m^{-1} treatment was significantly lower than other treatments (data not shown). There was also the production of nodal tillers, even after the flowering stage, as a result of high salinity level.

Biomass accumulation

In experiment 1, stress of 4 dS m^{-1} imposed at transplanting did not cause any significant effect on the biomass accumulation. Higher stress levels significantly decreased the biomass accumulation during the stress period at TP (Fig. 2). The values in Figure 2 are the mean values of four replications.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

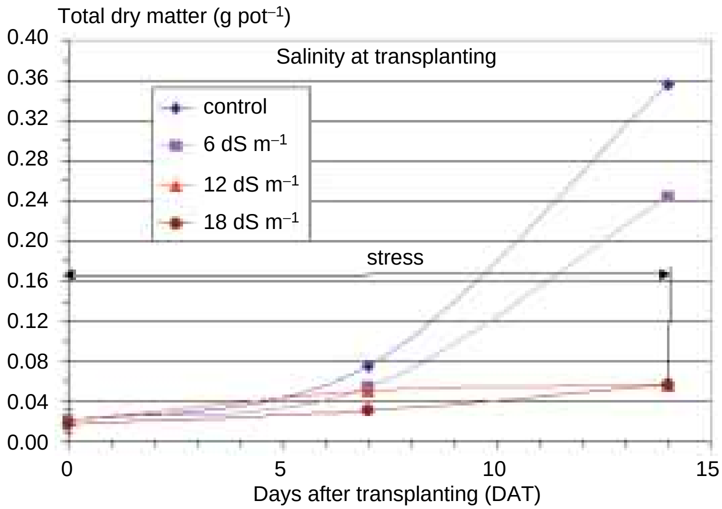

Figure 2. Effects of salinity stress imposed at transplanting on the total dry matter (IR64).

After the salinity stress period, the biomass accumulation showed a uniform pattern up to full maturity (Fig. 3). The difference in total above-ground biomass accumulation at maturity among the treatments was significant except for 12 and 18 dS m^{-1} treatments, which gave almost similar values in all sampling periods up to maturity. A similar trend was observed when salinity stress occurred at PI (Fig. 4).

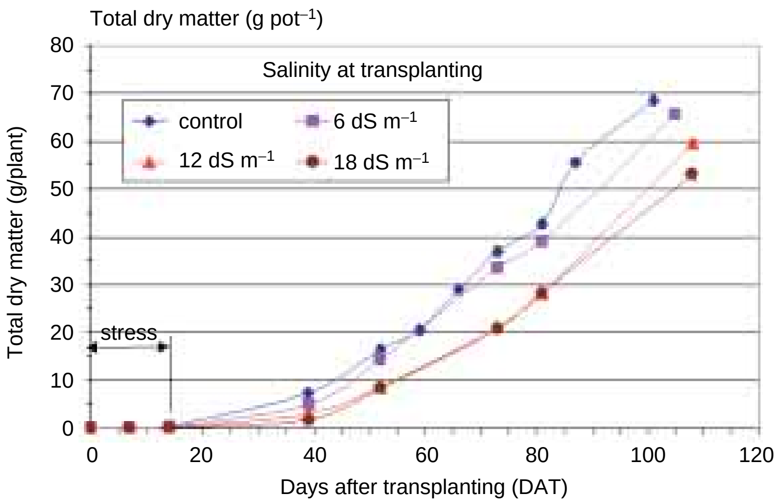

Figure 3. Total dry matter at different growth stages of IR64 after salinity stress was imposed at transplanting.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

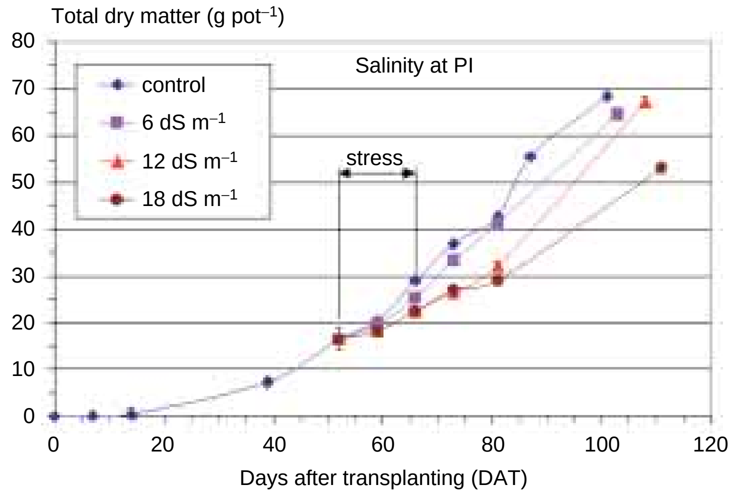

Figure 4. Total dry matter at different growth stages after salinity stress was imposed at panicle initiation (IR64).

The longer crop duration in the 12 dS m^{-1} salinity stress tests compensated for the loss of biomass accumulation during the stress periods and a final biomass equivalent to the control treatment could be obtained. Most of the biomass during this prolonged growth period resulting from the salinity stress, however, was accumulated in the nodal tillers but did not contribute to grain formation. In other words, stress at PI affected the partitioning of biomass into grain and straw.

Salinity stress imposed at the FL stage reduced the biomass accumulation during the stress period, resulting in lower total dry matter after the relief of stress (Fig. 5). A significant decline in biomass accumulation was observed for the 12 and 18 dS m^{-1} salinity levels at all sampling times up to maturity. The low dry matter at PM in the 18 dS m^{-1} was also due to the shortened duration of the crop.

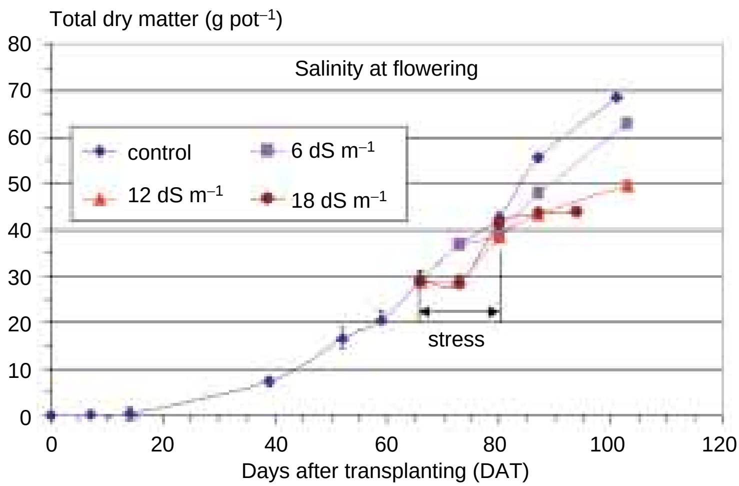

Figure 5. Total dry matter at different growth stages after salinity stress was imposed at flowering stage (IR64 phytroton experiment 1999).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Panicle number

From the nodal tillers, panicles were also formed. These were signified as nodal panicles to distinguish them from the normal panicles. Salinity levels 12 and 18 dS m^{-1} reduced the number of normal panicles. Salinity stress, particularly at PI, increased the number of nodal panicles significantly. When stressed at PI, most of the nodal panicles were formed during the grain-filling phase of the normal panicle crop. The results showing the effects of salinity stress on panicle development are shown in Figure 6.

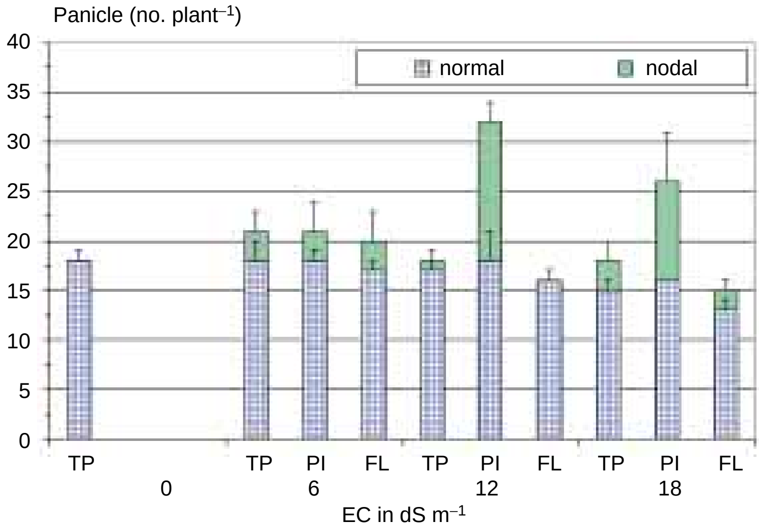

Figure 6. Effects of salinity stress on panicle numbers (IR64 phytroton experiment 1999).

Consistent with the reduced number of panicles, the numbers of spikelets on the normal panicles were also reduced at the stress levels of 12 and 18 dS m^{-1} (Fig. 7). High stresses at PI, however, increased the number of spikelets which formed on the nodal panicles after the relief of the stress.

Stress at PI hindered the formation of panicles and spikelets in the normal tillers, resulting in the reduced number of normal spikelets. The reduced sink was not adequate to store the carbohydrates, which were assimilated after the stress was relieved. Due to sink limitation, the assimilation formed the new nodal tillers, panicles and spikelets.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

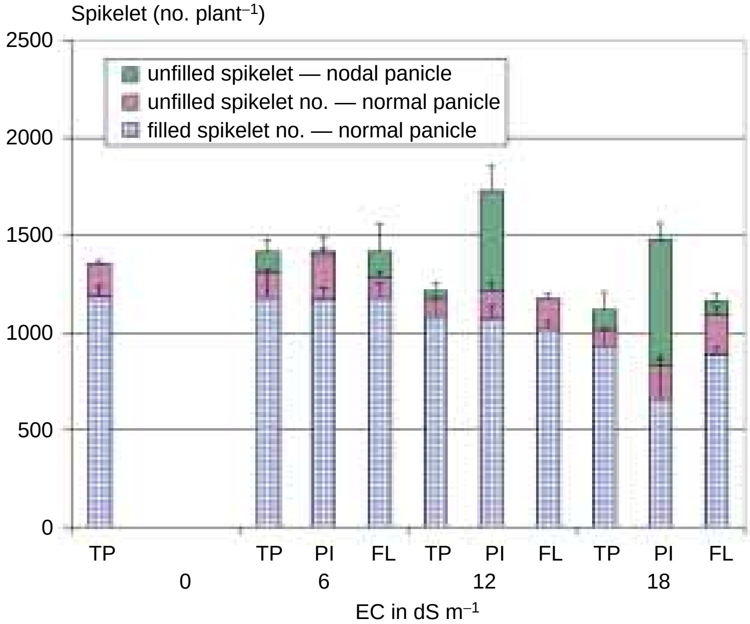

Figure 7. Effects of salinity stress on spikelet numbers (IR64 phytroton experiment 1999).

Grain yield

Grain yield at 4 dS m^{-1} (experiment 1) and 6 dS m^{-1} (experiments 2 and 3) salinity levels were not significantly different from those of the control. At higher salinity levels, grain yield declined as salinity increased (Fig. 8). At the higher salinity levels, the grain yield for plants stressed at PI and FL were consistently lower than those stressed at TP. At 12 dS m^{-1}, plants stressed at PI yielded similarly to those stressed at FL, but at a salinity level of 18 dS m^{-1}, grain yields for plants stressed at PI were significantly lower than for plants stressed at FL. The reduced yield from stress at PI was related to a reduction in the filled spikelet numbers, as shown in Figure 7. The vertical bars in Figure 8 indicate the standard errors (SE) of the mean of four measurements.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

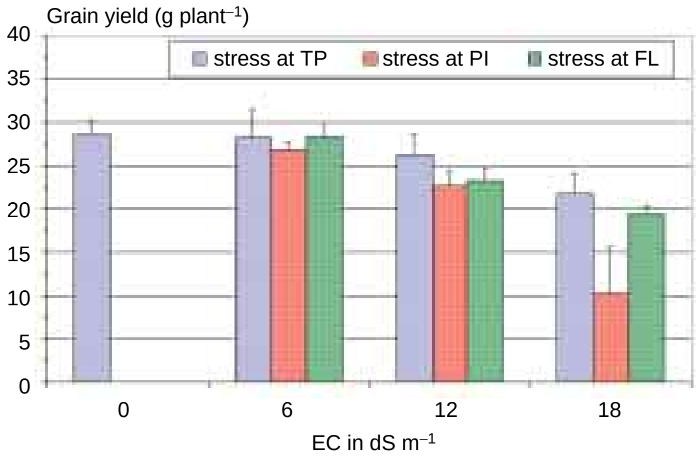

Figure 8. Grain yield of IR64 as affected by level and timing of salinity stress (Phytroton experiments 1999).

Uptake of nitrogen, phosphorus, potassium and sodium

The total uptake of nitrogen (N), phosphorus (P) and potassium (K) in the control and stress experiments is shown in Figure 9. In general, N, P and K uptake declined with increasing levels of salinity stress. At the same level of salinity, the uptake in plants stressed at FL was less than that of plants stressed at other growth stages. The significantly higher uptake of N and P in the straw of the plants stressed at 12 and 18 dS m^{-1} during PI was due to the uptake in the nodal tillers, which were formed after the relief of the salinity stress. This increase in N and P uptake, however, did not contribute to grain yield.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

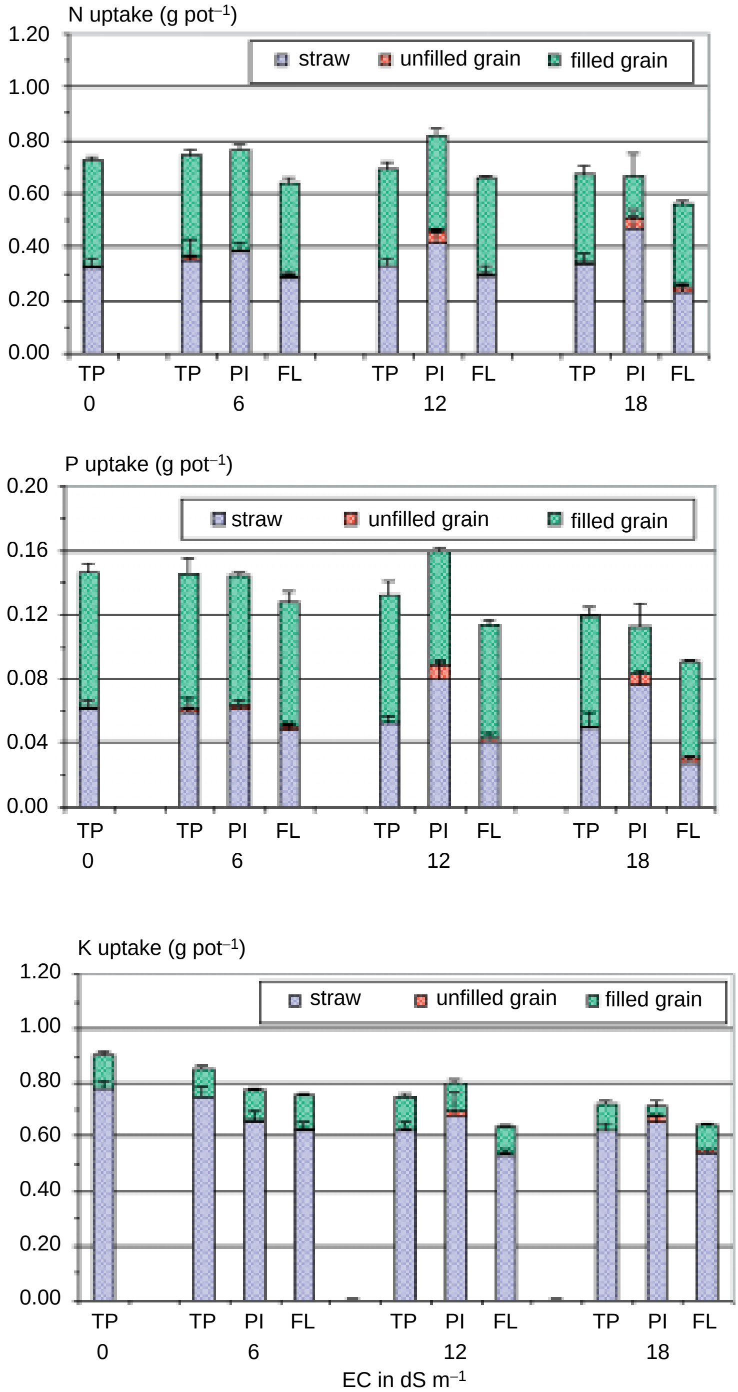

Figure 9. Effects of salinity stress on uptakes of N, P and K (IR64 phytroton experiments 1999).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Results from the phytotron experiments showed that almost the entire amount of sodium (Na^+) uptake resided in the straw (Fig. 10). The total uptake of Na^+ increased with the level of salinity stress. At the same level of stress, generally plants stressed at FL had higher Na^+ uptake than those stressed at PI and TP. The lower yield-associated stress at FL could be attributed to higher Na^+ uptake.

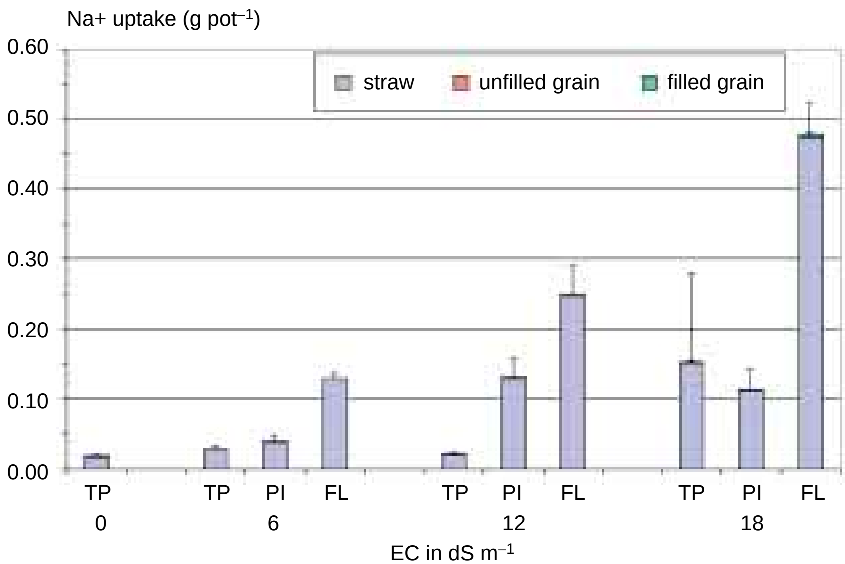

Figure 10. Effects of salinity stress for sodium (Na^+) uptakes (IR64 Phytroton experiments 1999).

Concluding comments

Salinity stress during the vegetative stage and at panicle initiation was found to delay flowering and prolong the crop duration. The prolonged duration increased the time for synthesis, which provided some compensation for the reduced assimilation during the period of salinity stress. Stress at transplanting, therefore, was found to have the least effect on biomass accumulation and yield of rice. However, dead leaves and tillers caused by high stress (higher than 8 dS m^{-1}) at transplanting was not compensated for and resulted in lower yields compared to the control.

Salinity of 12 dS m^{-1} and higher imposed at PI was found to hinder the formation of panicles and spikelets, creating sink limitation after the relief of the stress. Grain yield was greatly affected by the salinity stress, primarily because of the reduced number of filled spikelets resulting from the effects of salinity. Straw yield, however, was not negatively affected due to the development of late nodal tillers. High salinity levels (12 and 18 dS m^{-1}) after flowering had the effect of reducing the grain yield and total biomass because of the reduced duration of grain filling.

The responses of the rice plant to short duration salinity stress were found to be very similar to responses to drought. This is because salinity reduced the osmotic potentials of the soil solution. High sodium uptake in treatments with higher reduction in yield suggested that the yield reduction might have been caused by sodium toxicity.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

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Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 9

Assessing rice yield in rice–shrimp systems in the Mekong Delta, Vietnam: a modelling approach

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Abstract

The aim of this study was, by adapting the ORYZA2000 model, to quantify the response of rice to salinity stress and to quantify the yield variability in response to different sowing dates at the study sites of the ACIAR rice–shrimp project. The quantification of long-term rice yield in response to alternative management and salinity scenarios provides important information for selecting optimal rice-crop management options in rice–shrimp systems in the Mekong Delta. In the model it was hypothesised that the primary effect of salinity is similar to the water stress effect because salinity reduces the osmotic potential of the soil solution. The model converted the root zone salinity into osmotic potential and calculated the total potential of the soil solution. Using the known crop response to reduced potential (i.e. drought stress), the ORYZA2000 model calculated the effects of salinity on phenological, morphological and physiological development, biomass accumulation and grain yield of rice. The validation of the simulation results using data from the controlled phytotron and greenhouse experiments found that the model is able to simulate satisfactorily the effects of salinity on phenological development, biomass and yield reduction of rice cv IR64. The model was also able to explain yield differences of IR64 found at different locations from the rice variety field experiments conducted as part of the ACIAR rice–shrimp project. Using 10-year climatic and root zone salinity data for My Xuyen and Gia Rai, the model simulated the grain yields for different sowing dates (varying from 1 June to 1 September) and compared them with yields under salinity-free conditions. The simulated salinity-free yields ranged from about 5 to 6.3 tonnes ha^{-1} (with mean values from 5.3 to 5.8 tonnes ha^{-1}) at both My Xuyen and Gia Rai and declined slightly with late sowing dates. The simulated rice yield in rice–shrimp fields at My Xuyen ranged from 2.1 to 3.7 tonnes ha^{-1} and at Gia Rai from 1.1 to 2.5 tonnes ha^{-1}. The simulated mean yields for My Xuyen (2.8 to 3 tonnes ha^{-1}) did not change very much with the sowing dates. The results for Gia Rai suggest that the sowing date should be later than 1 August to avoid the risk of very low yield in years with low rainfall and high salinity.

TO EVALUATE THE economics of the rice–shrimp system and compare it with other land uses, it is important to assess the effect of salinity on rice performance in the rice–shrimp system in the Mekong Delta, Vietnam. Experiments can help evaluate the performance of rice in the system (Nguyen Ngoc De et al. this Report). Experiments are, however, site and time specific. It will be expensive to repeat the experiments at many sites (with different salinity dynamics), corresponding to various management options (such as changing the transplanting date). Furthermore, experiments will have to be carried out in many years to capture the long-term

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

variation in rice yield in the saline-affected fields. The above difficulties can be overcome by a systems approach, using simulation models. Such an approach has been widely used to investigate the long-term yields in highly variable rain-fed environments, and in response to various management options (Wopereis et al. 1995; Boling et al. 1999).

Previous researchers have attempted to use models to simulate the salinity effect on rice yield. Most earlier researchers (e.g. Walker et al. 1993; Singh et al. 1996) used the simple relationship that rice yield was not affected if the soil salinity was below a threshold value, and linearly decreased with salinity when it exceeded the threshold value. More sophisticated modelling approaches (e.g. Grand 1995; Beltrao and Asher 1997) used for other crops have not been developed for rice. Furthermore, most simulation studies for rice have assumed a constant salinity throughout the cropping season. Such conditions do not exist in the rice–shrimp fields in the coastal area of the Mekong Delta (Phong et al. this Report). The variation in salinity stress throughout the growing season and the variation in physiological response to salinity at different growth stages imply that we need a model that can predict rice performance (development, growth and yield) in response to the variable salinity in the rice–shrimp fields of the Mekong Delta.

The aim of this study was to adapt the ORYZA2000 model (Bouman et al. 2001) for simulating the effects of varying levels of salinity stress on the growth and development of rice crop and to use the model to assess the effect of the transplant date on long term rice yield in rice–shrimp fields in My Xuyen and Gia Rai in the Mekong Delta, Vietnam.

Materials and methods

Simulation approach

Salinity reduces the soil osmotic potential (Chhabra 1996) and therefore reduces water availability for crops. One of the primary effects of increased salinity in the root zone is thus the water stress, similar to the drought effects (Grant 1995). We hypothesised that salinity effects on growth of rice can be simulated by the same water stress functions relating the crop growth and development to reduced soil potential (Wopereis et al. 1996b; Tuong et al. 1996).

The ORYZA2000 model

ORYZA2000 (Bouman et al. 2001) is an updated and integrated version of the ecophysiological models ORYZA1 (Kropff et al. 1994) and ORYZA_W (Wopereis et al 1996a). ORYZA2000 simulates crop growth and development of lowland rice in potential and water-limited production situations. Under potential situations, water and nutrients are in ample supply and growth rates are determined by weather conditions only (radiation and temperature). Under water-limited production, growth is limited by water shortage in at least part of the growing period, but nutrients are still considered to be in ample supply.

ORYZA2000 consists of separate modules to calculate growth and development of the crop, evapotranspiration and effects of reduced soil potential (water stress) on growth and development. The crop module is a photosynthesis-driven model with daily time step. The daily canopy assimilation rate is calculated by integrating the calculated photosynthesis of single leaves over the height of the canopy and over the day. After subtracting respiration requirements and accounting for losses from the conversion of carbohydrates into structural dry matter, the net daily growth rate is obtained. The dry matter produced is partitioned among the various plant

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

organs according to the stage of development of the crop, which is tracked as a function of ambient mean daily air temperature.

To simulate the effects of salinity, a SALT module was added which can calculate the osmotic potential due to the presence of salts, which is represented by the following formulae (derived from a graph in Chahabra 1996).

$$\frac{OSMKPA = 100*(EC^{1.12})}{3.8}$$

where OSMKPA is the osmotic potential (in kPa) and EC is the electrical conductivity of the solution (in dS m^{-1}). The model added the osmotic potential to the matrix potential (input or simulated by the model) to get total soil–water potential.

Effects of reduced potential (i.e. water stress) on crop growth and development include leaf rolling, reduced leaf growth rate, accelerated leaf senescence, reduced evapotranspiration and photosynthesis, reduced development rate, reduced sink size, and spikelet fertility. The water stress response functions, relating crop growth and development parameters with soil potential, were derived from drought experiments in pots (Wopereis et al. 1996b; unpublished experiments by the authors) and from Turner et al. (1986).

In the rice–shrimp system, the field is always kept flooded, and so osmotic potential is the only component of the soil–water potential. In this case, ORYZA2000 requires input data on physiological characteristics, crop management (e.g. sowing and transplanting date), daily climatic data and daily salinity of each soil layer within the root zone.

Model evaluation

ORYZA2000 was evaluated using the data from the phytotron experiment on effects of salinity levels and timing on the development and growth of rice cultivar IR64 (Castillo et al. this Report). The input data included date of sowing, date of transplanting, salinity levels (EC 6, 12, and 18 dS m^{-1}), timing of salinity stress (at 1 day after transplanting (DAT) at panicle initiation (PI) and flowering (FL)); duration of salinity stress (14 days, except for EC 18 dS m^{-1} which was imposed at 1 DAT for 7 days) and the daily climatic data. For the crop, standard physiological characteristics for IR64 were used (IRRI, unpublished data set).

The computed dates using the ORYZA2000 model for PI and FL of the control and of the salt-stressed treatments were compared with their corresponding observed dates. The unit of measurement for the simulated biomass and grain yield was in kg ha^{-1}, while the experiment data from Castillo et al. (this Report) were measured per pot. These data, therefore, could not be compared directly, which meant that we needed to compare the simulated relative biomass and grain yields with the corresponding measured values. The relative biomass (or grain yield) was defined as the ratio between the biomass (or grain yield) of the salt-stress treatments and that of the salt-free treatment.

The model was also evaluated with data from the 1998 field variety testing in My Xuyen and Gia Rai for rice–shrimp and rice monoculture fields of the rice–shrimp project. These field experiments were described in Nguyen Ngoc De et al. (this Report). The data included the date of sowing and transplanting, the daily climatic data of Soc Trang (for the My Xuyen site) and Bac Lieu (for the Gia Rai site), and the daily salinity of soil layers within the root zone for experimental field (Ngo Dang Phong et al. this Report). The model was evaluated using the experimental yield data for cv IR64 only, as there was not data available on the physiological characteristics for other rice varieties.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Simulation scenarios

The model was used to simulate the response of rice yields to variation in sowing dates in rice–shrimp fields as well as in salt-free fields — in My Xuyen for the period 1990–1999 and in Gia Rai for the periods 1988–1989, 1992–1999. The date of sowing was varied for each year in 15-day steps from 1 June to 1 September. In the crop input files, we adjusted the canopy nitrogen so that the potential yields (i.e. the salt-free yields) were at 5–6 tonnes ha^{-1}, which was a good yield of the same cropping season reported in areas of the Mekong Delta not affected by saline intrusion. The daily climatic data were used as inputs at Soc Trang for My Xuyen, and at Bac Lieu for Gia Rai. The salinity of the soil layers within the root zone at each site (generated values for 10 years, Phong et al. this Report) was used as input for the simulation. The simulation results were subjected to frequency analysis using a gamma distribution model (Thom 1968).

Results and discussions

Model evaluation

Although a full statistical analysis of model performance is not presented here, the preliminary results outlined below indicate that ORYZA2000 performed sufficiently well for the purposes of this study.

In Figure 1, the simulated dates of PI, FL and physical maturity (M) are compared to the observed dates from the phytotron experiments conducted at IRRI as outlined in Castillo et al. (this Report). The model adequately simulated the delay of flowering and maturity of the saline-stressed plants. However, the model could not simulate the observed effect of the salinity at flowering stage in shortening the period between flowering and maturity as described in Castillo et al. (this Report). The discrepancy, however, was only a few days and would not greatly affect the computed biomass accumulation and yield.

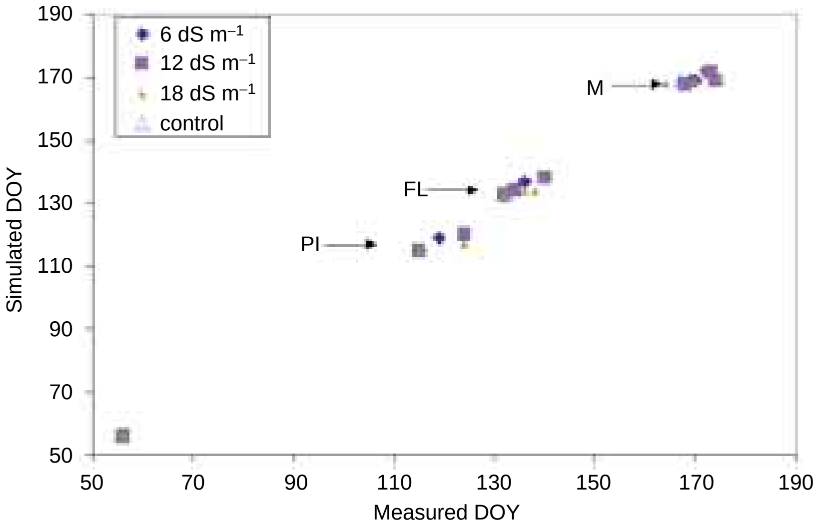

Figure 1. A comparison of simulated and observed phenological development in rice under saline stress. DOY = day of the year; PI = panicle initiation; FL = flowering; M = maturity.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

In Figure 2, it is shown that, for most cases, the model satisfactorily simulated the relative biomass and grain yield. In the high-salinity cases (12 and 18 dS m^{-1}), the model slightly underestimated the relative grain yield and relative biomass of the plants stressed at PI and FL stages; however, the difference between the computed and the observed values was not much greater than the coefficient of variation of the observed values.

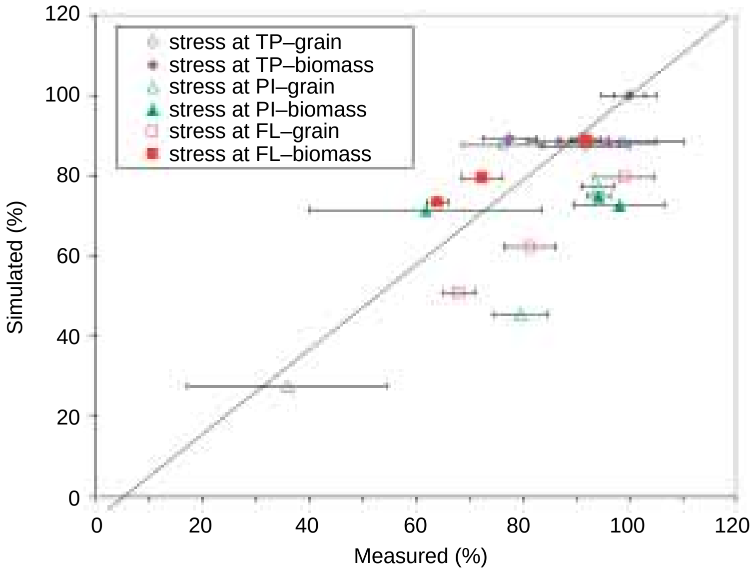

Figure 2. Simulated and observed results for relative (salt-affected yield divided by salt-free yield) grain and biomass yield. TP = at transplanting; PI = panicle inititation; FL = flowering.

In Figure 3 the simulated rice yields are compared to observed yields from field experiments in rice–shrimp and rice monoculture fields in My Xuyen and Gia Rai. Some differences between the simulated and observed rice yields are expected due to crop management factors (e.g. nutrient management, pest and diseases) that could not be fully taken into account in the simulation. On the whole, except for field D in Gia Rai (GRD in Fig. 3), the simulated yield varied with the same trend as the observed yields. It was confirmed by the simulation that the very low yields in field A and B in Gia Rai (GRA and GRB in Fig. 3) were mainly due to very high salinity.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

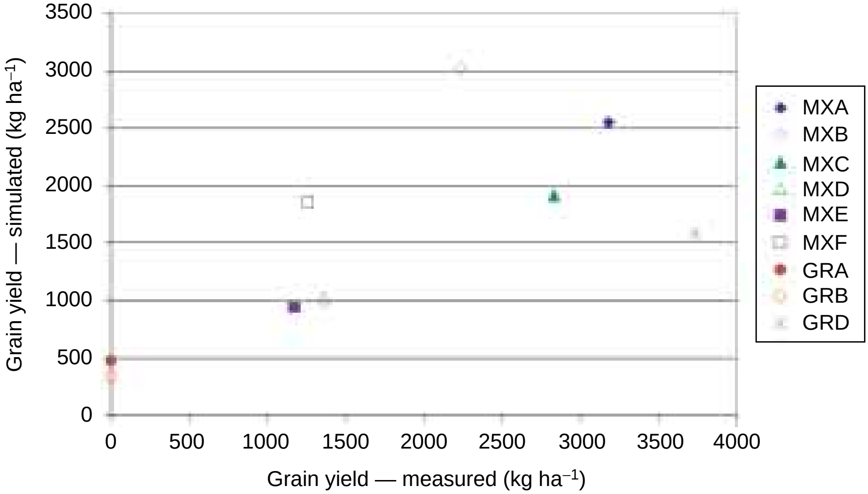

Figure 3. Yield comparison for My Xuyen (MX) and Gia Rai (GR). A, B, and C are rice–shrimp fields; D, E and F are mono-rice fields.

Variation in yield with respect to date of planting

The simulated potential and salinity-affected yields for My Xuyen rice–shrimp fields are shown in Figure 4 for alternative sowing dates in 1998. The difference between the potential and the saline-affected yield was about 2.5 tonnes ha^{-1}. In general, the potential yield decreased as the sowing date was delayed from 15 June to 1 September. As radiation decreases with the progress of the rainy season crops planted later in the rainy season, receive less radiation, and therefore potential yields were lower compared to those planted earlier in the rainy season.

In 1998, the salinity-affected yield increased slightly with the delay of planting. This can be largely explained by: (a) decrease in radiation and (b) decrease of salinity towards the end of the rainy season. The increase in yield towards the later planting dates indicated that the effect of (b) was stronger than that of (a).

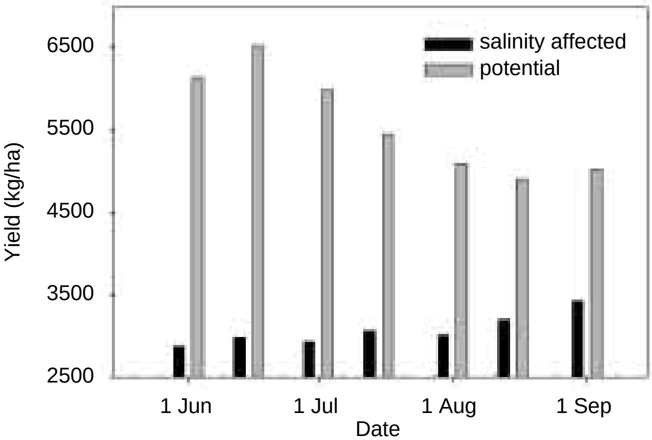

Figure 4. Simulated potential and salinity-affected yield as affected by date of sowing, My Xuyen, 1998.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Long-term rice yield in rice–shrimp systems

The probability distribution for potential yield and yields in the rice–shrimp fields in My Xuyen and Gia Rai are presented in Figures 5 and 6. The probability curves were derived for different sowing dates from 10-year simulated yields. The probability of exceeding the simulated yield is depicted. The group of probability lines at the top of the Figures is that for potential yield; the lower group is for the saline-affected yield. The potential yields at both sites ranged from 5 to 6.3 tonnes ha^{-1}. There is a tendency for the simulated potential yields to decline when sowing date is delay. This was more pronounced in Gia Rai (Fig. 6) compared to My Xuyen (Fig. 5). As explained earlier, this decrease was due to the decline in radiation in the later part of the rainy season.

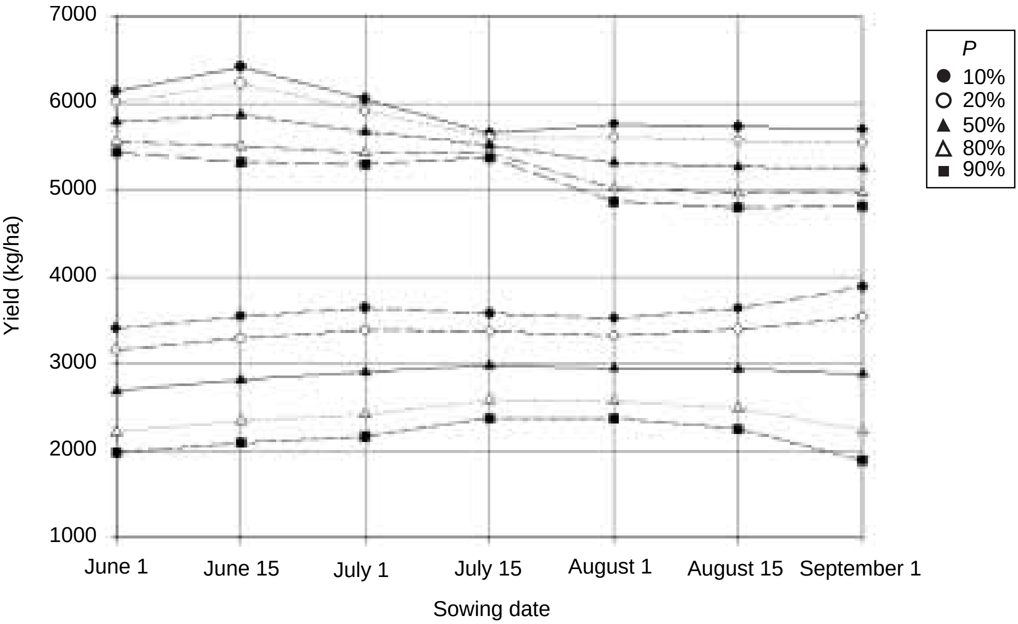

Figure 5. Simulated probability of exceedence (*P*) distributions for potential yields (lines at the top of the figure) and yields in rice–shrimp systems (lines at the lower portion of the figure) in My Xuyen.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

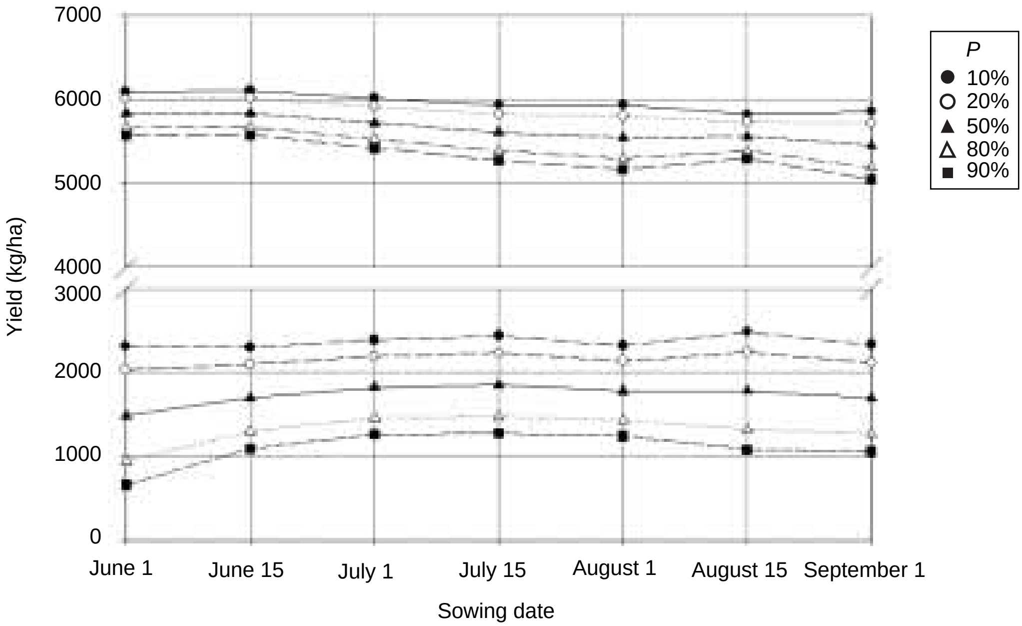

Figure 6. Simulated probability of exceedence (*P*) distributions for potential yields (lines at the top of the figure) and yields in rice–shrimp systems (lines at the lower portion of the figure) in Gia Rai.

The salt-affected yields for the My Xuyen rice–shrimp fields ranged from about 2.1 (at probability of exceedence 90%) to 3.7 tonne ha^{-1} (at probability of exceedence 10%). The corresponding values for Gia Rai were 1.1 and 2.5 tonnes ha^{-1}. The difference between Gia Rai and My Xuyen is mainly attributable to much higher salinity levels in Gia Rai (Phong et al. this Report).

In both My Xuyen and Gia Rai, the yield at 90% probability of exceedence increased when the sowing date was delayed from 1 June to around July to August. Early sowing (before 1 July) ran into the risk of early salinity, which affected the yield in years with late arrival of the rainy season. Delaying the sowing date beyond 1 August (i.e. transplanting later than the end of August) may expose the end of the crop to the risk of high salinity levels if the rainy season recessed early. In My Xuyen, however, it is predicted that a delay in the sowing date until 1 September in some years (with a prolonged rainy season) would result in an increased rice yield (at a probability of 10%, Fig. 5).

Conclusions

Although the ORYZA2000 model did not take into account the toxicity effect of long-term salinity stress, the results indicate that the model performed sufficiently well for the purpose of generating the long-term probability distribution of rice yields in the rice–shrimp system. At both sites, the model predicted that the best time for sowing to avoid heavy yield losses in years with high salinity is from 15 July to 1 August.

The simulation results are valid only for the variety that the model was developed and evaluated for (cv. IR64) and for the locations where salinity data were measured or derived. The methodology presented, however, was generic and is applicable for other varieties and locations.

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Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 10

Factors affecting farm financial risk: observations from a bioeconomic model

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Abstract

In this paper, a bioeconomic model is used to examine the consequences of risky shrimp yield on household income. The model depicts the production and farm management characteristics of the farm household, and accounts for risky yield of shrimp and rice. The consequences of downside yield risk on income include reduced household consumption and low level of working capital to finance the subsequent season's production. The model is used to calculate the probability distribution of income for different scenarios, to illustrate the importance of various factors on farm household income risk. These factors include shrimp survival, shrimp-stocking density, income diversification and obtaining credit to supply working capital in the event of a shrimp-crop failure. Also examined are issues relating to the choice of species, such as mixed versus monodon-only systems, and alternatives to monodon. Results indicate that the choice of stocking density, of whether to use credit and of whether to adopt recommended management practices depend on the circumstances of the individual farmer, including risk preferences, other sources of income and expected shrimp survival.

IN THIS PAPER, bioeconomic modelling tools are used to assess the impact of various factors on farm financial risk and farm performance. Bioeconomic modelling involves mathematical representation of the physical and economic factors affecting farm income. These tools are generally used to provide economic assessment of farm management options, where the relationship between physical inputs and outputs are represented from underlying biophysical models. These biophysical models can vary in their degree of sophistication from simple models of relationships based on 'expert opinion' to detailed mechanistic models of biophysical processes. Bioeconomic models generally use either optimisation techniques to solve to the 'best farm management choice', or simulation techniques to assess the sensitivity of farm income to various farm management options. Simulation techniques are normally used where the emphasis is on income risk, which is the case in this study.

The outline of the paper is as follows. First, the components of the bioeconomic model, including growth, survival and yield relationships, and farm management assumptions are outlined. Then results of monte carlo simulations of farm income risk are presented, which analyse the effect of various factors on income risk. These factors include shrimp survival, shrimp-stocking density, income diversification and obtaining credit to supply working capital in the event of a shrimp crop failure. Also examined are issues relating to the choice of species, such as mixed versus monodon-only systems, and alternatives to monodon.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

Model description

The bioeconomic simulation model generates a sequence of farm household income estimates, based upon underlying models of shrimp and rice yield, and other factors affecting household income. The equations and underlying assumptions used in simulating farm income are described in this section.

Farm income

The net cash income for the farm household is the sum of income from the various activities conducted by the household. These include shrimp farming, rice production, upland agriculture (conducted on the banks or on higher ground in the wet season), other aquatic production (generally fish, freshwater prawn, crab) and income earned from off-farm activities, as shown in Equation 1.

$$\tilde{Y}_{tot} = \tilde{Y}_{shrimp} + \tilde{Y}_{rice} + \tilde{Y}_{otherfarm} + \tilde{Y}_{off\text{-}farm} \quad (1)$$

where Y refers to income and the tilde above the Y denotes a risky income component.

Because the emphasis in the model is on rice and shrimp, and because there is insufficient detail about the reliability of the other sources of income, these other components are assumed to be constant in the analysis. In the next sections, the modelling of income from shrimp and rice is described.

Shrimp income

Income from shrimp production is described in equation 2, the main variable costs are feed (if used) and shrimp postlarvae.

$$\tilde{Y}_{shrimp} = P_s.Q_s - c_s.S - c_f.F - O_{shrimp} \quad (2)$$

where P_s is the price of harvested shrimp
Q_s is total shrimp produced
S, F are amount of shrimp stocked and feed used
c refers to per unit costs of input
O is other costs, assumed to be fixed (polder preparation etc.).

Assumptions for the costs of inputs and polder preparation costs are derived from the baseline survey (Brennan et al. 1999).

Shrimp price

Survey data was also used to estimate an equation describing shrimp prices as a function of shrimp size. The regression equation (R^2 = 73%) was:

$$P_s = 179542 - 3162.C + 17.4\,C^2 \quad (3)$$

where C is class (number of individuals per kilo) and price is in dong per kilo.

Shrimp production

Total shrimp production depends on the total number stocked, the number surviving until harvest, and the growth rate, hence final weight, of the shrimp.

$$Q_s = S.\phi.w \quad (4)$$

where S is (initial) stocking density
ϕ is survival (number harvested/number stocked)
w is average harvest weight of individual shrimp

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Monodon growth rates

There are many models available to explain individual shrimp growth in intensive systems (Adams et al. 1980; Griffin et al. 1984; Jackson and Wang 1998). These models generally describe an asymptotic growth rate which is affected by factors such as water quality and stocking density. Jackson and Wang's model described monodon growth rate as a function of water temperature, salinity and mortality. They interpreted their mortality factor as a proxy for effective stocking density, as higher mortality led to faster growth. The 'stocking density' factor was used to extrapolate growth rates for the stocking density used on the rice–shrimp farm (around 2 PL/m^2). While this represents an extrapolation below the range of data used by Jackson and Wang (the lower range of effective stocking density was about 8 PL/m^2), the estimated growth rates were consistent with observed rates in rice–shrimp experimental ponds. The estimated growth curve is shown in Figure 1, which was calculated using daily temperature and salinity measures from the data-logging experiment described by Minh et al. (this Report). Data points indicating measured shrimp growth rates at various intervals during the shrimp pond experiment are also shown, and follow the estimated curve reasonably well.

A number of additional assumptions were required to complete the model of shrimp growth. First, because of a lack of time series data on pond conditions, the effect of variation in pond temperature and salinity were controlled for (i.e. set equal to mean observed rates), to provide a simplified version of the growth model shown in Equation 5. Second, because of the difficulty in getting accurate data at lower weights, the growth model used here predicts growth of shrimp once they are past a body weight of 3.5 g. To complete the growth model, it was necessary to make an assumption about the time taken to reach 3.5 g. Based on observed experimental data this was assumed to be 40 days after stocking.

$$w_t = 55.\left[\frac{3.5}{55}\right]^{e^{-a(t-40)}} \tag{5}$$

where a = 0.016637 and t is total crop length.

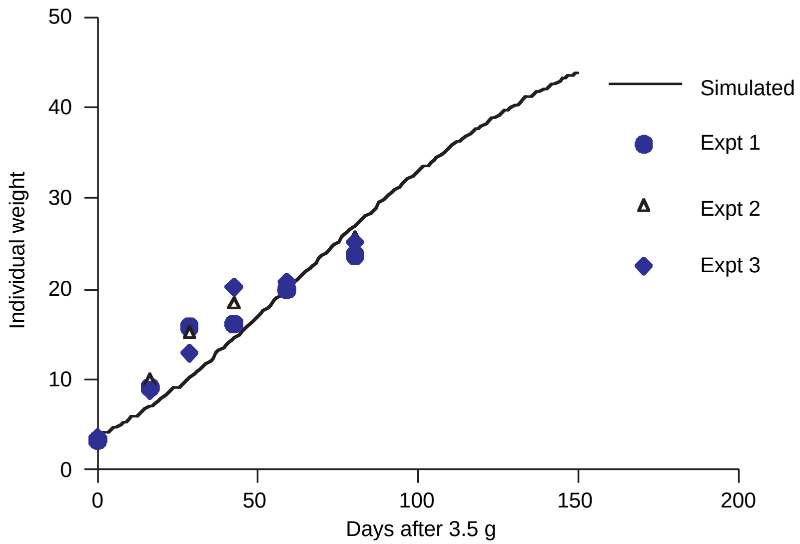

Figure 1. Shrimp growth: Model projection and growth in experimental ponds.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Survival

Poor shrimp survival is one of the main factors affecting income from shrimp production. While quantitative scientific evidence of the importance of various factors affecting shrimp survival is scant, animal health experts have developed ‘best management practice’ advice that summarises the current state of knowledge. The main cause of poor survival in Asian farming systems is believed to be disease, and one of the most devastating of these is white spot disease. White spot disease has been verified as a problem in the Mekong Delta. Best management practices are aimed at reducing the pathogen load in the pond and reducing the expression of the disease by growing the shrimp under optimum environmental conditions.

The best opportunity for reducing pathogen load is to use new DNA-testing techniques that can test for the presence of the white spot virus. Withyachumnarnkul (1999) provided evidence to support the reduced risk associated with exclusion of white-spot-infected postlarvae. In a study of intensive shrimp ponds in Thailand, he found that only 5% of intensive ponds stocked with one-step PCR-positive postlarvae reached a profitable harvest, compared with 69% for ponds stocked with one-step PCR-negative postlarvae. In the longer term, such testing strategies will help to reduce the risk associated with shrimp stocking, but at present these technologies are not available to farmers in the Mekong Delta.

At present, technology for eliminating white spot from stocked shrimp is not widely available in the Mekong Delta. However, even if it were possible to stock with disease-free shrimp, there are other components to the ‘best management practice’ recommendations that need to be considered, which focus on reducing pathogen load from other sources. In particular, it is recommended that intake of disease carriers (particularly other crustaceans) should be minimised by appropriate management. Recommended practices aimed at reducing pathogen load are reduced water exchange and construction of fences to exclude crabs from the pond. However, it can be noted that farmers rely quite significantly on diverse income sources as a means of managing risk, and one important source of other income is the harvest of other crustaceans. This practice is not consistent with the ‘best management practice’ of minimising pathogen load by removing other crustaceans. This issue is explored below in ‘Monodon production under quarantining strategies’.

Because of the lack of quantitative data on the effect of farm management on shrimp survival in Mekong Delta conditions, survival in this analysis is treated as a random factor, outside control of management. Survival in a particular season is obtained by taking a random number between zero and one and looking up the survival corresponding to an assumed cumulative probability distribution. Observed cross-sectional data on shrimp survival from the 1997 farm survey was used to represent the probability distribution of survival. Because of the significant difference between the performance of farms in My Xuyen and Gia Rai, these data are treated separately in the analysis and used to represent relatively ‘good’ and ‘poor’ survival in different model runs. The probability distributions are shown in Table 1.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 1. Probability survival tables used in risk analysis.

	My Xuyen		Gia Rai	
State	Probability	Survival %	Probability	Survival %
1	0.069	0	0.258	0
2	0.158	10	0.318	5
3	0.149	20	0.167	10
4	0.218	30	0.083	15
5	0.139	40	0.114	30
6	0.099	50	0.061	50
7	0.069	60		
8	0.099	75		
Mean		33		11

Source: Household survey (Brennan et al. 1999).

Production of natural shrimp

Farmers in both districts obtain income from recruitment of natural shrimp. In Gia Rai, farmers tend to actively recruit shrimp all year round, including during the time that monodon is stocked. In contrast, farmers in My Xuyen tend to practise low-water exchange during the dry season when monodon are stocked, and natural shrimp yields are very low. The abundance of natural shrimp in the My Xuyen District is also believed to be lower, so the total yield of natural shrimp in that district is relatively low. Because the disease outbreaks that occur tend to affect natural shrimp as well as monodon, it is assumed that the survival of shrimp follows the same pattern as for monodon.

Rice Production

Farmers grow rice for subsistence needs and sell the surplus for cash. The total income from rice production in this analysis includes the value of production for subsistence as well as cash.

$$\tilde{Y}_{rice} = P_R.\tilde{Q}_R - VC \qquad (6)$$

where Q_R is rice production and VC is variable cost per farm.

Brennan et al. (1999) found that variable costs of rice production were fairly homogeneous between farms in particular villages, but there was significantly less expenditure on fertiliser and other inputs in Gia Rai compared to My Xuyen. The variable costs of rice production are based on those found in the survey and are represented in Table 2.

Rice yield

The model described by Tuong et al. (this Report) was used to represent rice yield. In their model, the salinity-affected rice yield depends on the timing of planting and the climatic factors for a particular year, which affect the potential yield as well as the soil salinity, both at the time of planting and throughout the production cycle. In the analysis conducted in this paper, a planting date of mid-July is assumed, and a probability distribution for rice yield based on

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

that planting date was calculated for each site. The associated probability distribution of yield for a plant date of mid-July is shown in Figure 2.

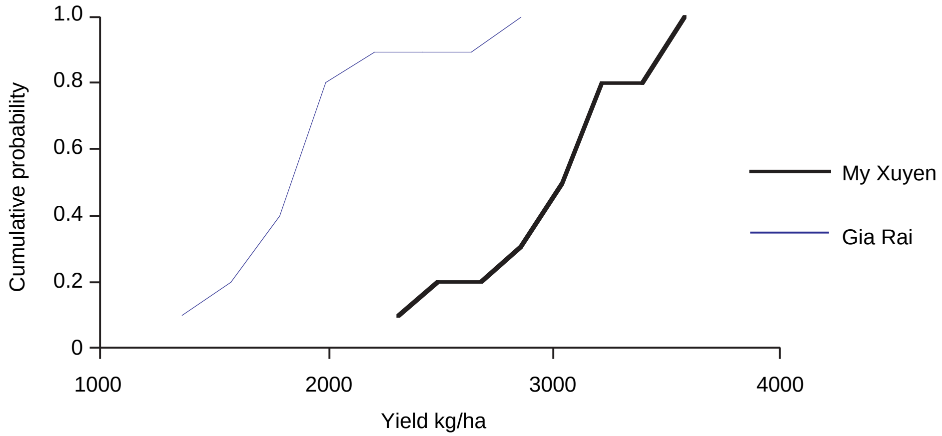

Figure 2. The probability distribution of rice yields used in the monte carlo simulation.

Household decision making

The production of monodon requires significant operating capital at the beginning of the shrimp season, and is subject to large yield risk. Thus, in a season where low or zero survival is experienced, the farmer suffers large financial losses. These losses can impact on household consumption, and can also affect the future production by limiting the availability of working capital in the following season. A sequence of poor years can lead to a build-up of indebtedness and eventually farm financial failure.

In order to simulate the income risk of a rice–shrimp farm, it is necessary to make assumptions about the allocation of cash between household consumption and investment in shrimp stocking (intensity). The following behavioural assumptions are used. First, it is assumed that farmers allocate a minimum amount of available cash to household consumption with the remaining amount being available to finance shrimp stocking. When the available surplus is not sufficient to finance the desired stocking rate, stocking is reduced or, in some scenarios, funds are borrowed to make up the difference. In the simulation, household consumption can fall below the minimum basic consumption in cases where other sources of income are relatively low and when funds invested in shrimp are relatively large and survival is low. A sequence of 1000 simulations is calculated where the outcome from one season is used to imply funds available for consumption and stocking in the subsequent period. Results are presented in terms of the probability distribution of annual household cash income.

Other parameter assumptions

To complete the farm household income calculation, it is necessary to represent other farm income and income earned off the farm. In the following analysis, two scenarios are presented, representing the contrasting alternatives of a well-diversified and a poorly diversified household. The base assumption assumes a well-diversified farm, and parameter assumptions were derived from survey data. The well-diversified farm is assumed to have off-farm income, upland cropping

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

and other types of aquaculture (natural shrimp and machrobrachium in My Xuyen, crab in Gia Rai) with values based on average figures from the survey. These estimates are shown in Table 2 along with other parameter assumptions associated with rice and shrimp production.

Table 2. Basic assumptions for representative farms*.

	My Xuyen	Gia Rai
PL price (dong)	200	100
Feed cost ('000 dong/kg)	15	0
Feed Conversion Ratio	1	n/a
Other shrimp costs ('000 dong/ha)	1 325	1 372
Monodon price ('000 dong/kg)	100	100
Natural shrimp yield (kg/ha)	55	192
Natural shrimp price ('000 dong/kg)	22	22
Rice price ('000 dong/kg)	1.6	1.6
Rice variable cost ('000 dong/ha)	2 036	1 729
Upland net income ('000 dong/ha)	700	460
Other aquaculture ('000 dong/ha)	500	1 300
Minimum consumption** ('000 dong per annum)	8 000	8 000
Other farm income ('000 per household)	4 400	5 200
Expected household income at 2 PL/m^2	18 832	14 546

* Source: 1997 household survey of farms in My Xuyen and Gia Rai (Brennan et al. 1999).
** Assumed amount of last years' farm cash income set aside before investment in monodon occurs.

Results

In this section, the bioeconomic model is used to explore the implications of shrimp yield risk on farm household risk. Several strategies for reducing or managing risk are demonstrated. Further results can be found in Brennan (2002), in which optimal farm savings strategies for different risk preferences are illustrated.

Impact of stocking density on household income

The farmers can select the amount of risk that they wish to bear by choosing the level of intensity at which they operate. For example, a lower stocking intensity will lead to lower financial losses if the crop fails. Farmers can also limit their expenditure on feed (although the production implications of alternative feeding regimes could imply that this strategy is counterproductive; for evidence, see Brennan et al. 2000). The selection of lower intensity can also be a consequence of financial constraints rather than risk aversion.

The effect of stocking density on the probability distribution of income is presented in the following figures, where baseline assumptions concerning other sources of farm income (as indicated in Table 2) are used. Results for the My Xuyen case are shown in Figure 3. According to stochastic dominance principles (e.g. Hardaker et al. 1997), it can be concluded that none of the scenarios is preferred over the others; in other words, the preferred stocking strategy would depend on the risk preference of the farmer. The income distribution lines cross at about the 20% probability level, corresponding to an income level of about 10 million dong. The degree of income loss below this level is higher where stocking rate is higher, for any probability level. Conversely the income earned in years of good survival is very high in the case of higher stocking intensities. The more the farmer weights very low income levels, the less likely is he to practise high stocking rates.

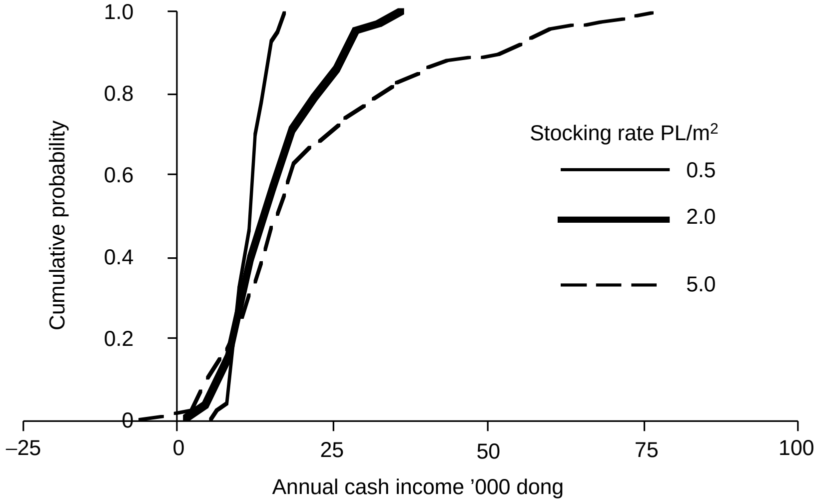

Figure 3. Income risk for 3 stocking rates, My Xuyen.

Similar results are shown in Figure 4 for the typical Gia Rai farmer. These farms have a higher probability of experiencing very low income levels, and this is particularly pronounced for the case of the highest stocking density. The risk-averse Gia Rai farmer is less likely to adopt higher stocking intensities than the My Xuyen farmer.

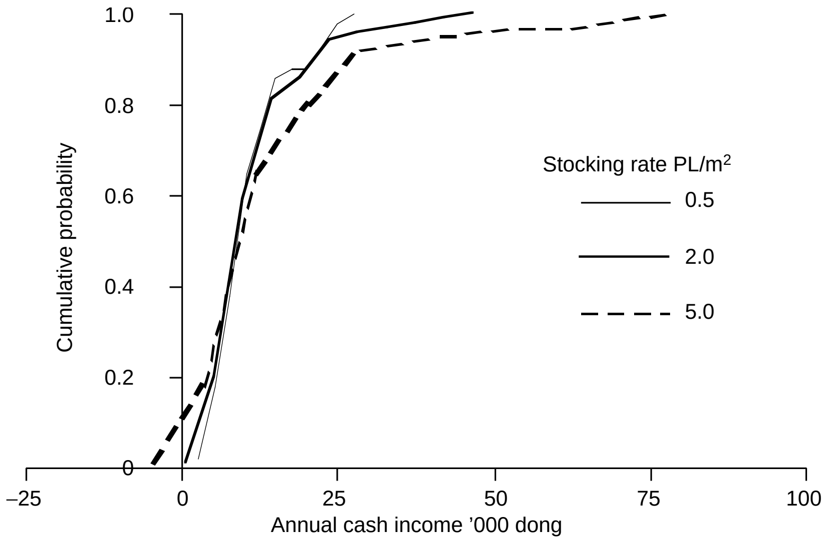

Figure 4. Income risk for 3 stocking rates, Gia Rai.

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edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Mean income results for both the My Xuyen and Gia Rai scenarios are summarised in Table 3. Also shown are the mean levels stocked, which are affected largely by the availability of cash. As discussed earlier, it is assumed that the farmer allocates cash to shrimp stocking after setting aside a minimum amount (8 million dong) for household consumption. The effect of poor yields on subsequent ability to finance stocking is seen by comparing actual and desired stocking levels. The probability that income falls below this benchmark level of 8 million dong is also shown. The relatively poor performance of the Gia Rai farms is illustrated — there is a 30% chance that income falls below the benchmark level for all stocking rate scenarios. This indicates the high degree of risk that is being taken on by farmers practising rice–shrimp culture in this region.

Table 3. Mean income and stocking rates for the representative farms under different stocking rate scenarios.

District	Stocking rate		
	0.5	2	5
My Xuyen			
Mean income (in million dong)	11.0	15.2	20.3
Mean stocked	0.373	1.152	2.072
P (income < 8 million dong per household)	0.04	0.08	0.11
Gia Rai			
Mean income (in million dong)	10.1	10.9	12.4
Mean stocked	0.274	1.006	2.117
P (income < 8 million dong per household)	0.35	0.33	0.37

Importance of other sources of income

The high degree of risk means that non-shrimp sources of income will provide an important source of funds, both for consumption and for investing in shrimp postlarvae. This is illustrated in Figure 5, where the income probability distributions are calculated for three scenarios reflecting different levels of income diversification. These are the base case scenario where the farmer has off farm and other farm income; the case where the farmer has no off-farm income; and the worst case scenario where the farmer has no off-farm nor any other source of on-farm income besides rice and shrimp. The My Xuyen case, with an assumed stocking rate of two postlarvae per square metre is shown. The impact on the probability distribution of income is more pronounced than a simple shifting of the curve. This is because of the impact of poor shrimp survival on the ability to finance shrimp stocking in subsequent years when there are no other sources of income. The undiversified farms have much steeper curves over the range of probabilities below the 90th percentile, whereas above this percentile the probability distribution is very spread out. This region of the curve reflects the area where the farmer can afford to re-invest in shrimp. Mean results and average stocking rates are also shown in Table 4.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

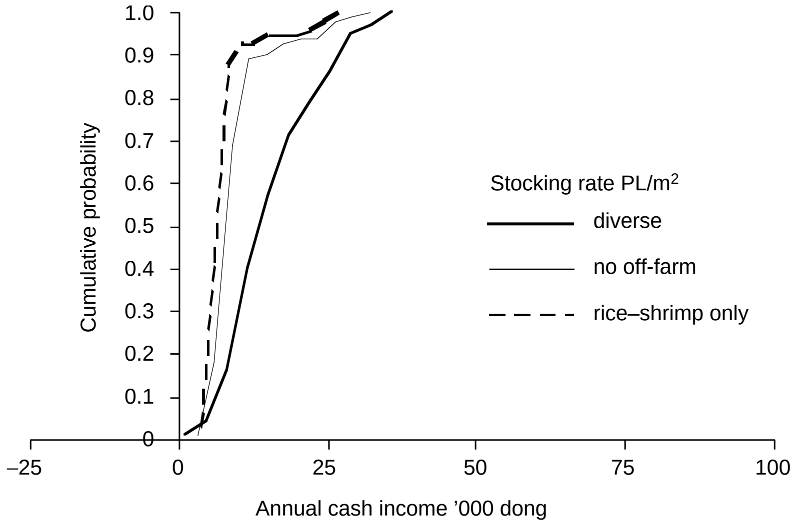

Figure 5. Comparison at different levels of 'other income', Stocking rate 2PL/m^2, My Xuyen.

Table 4. Stocking rates achieved for different farm types when maximum stocking rate is set at 2 PL/m^2.

	Well diversified	No off-farm	Rice–shrimp only
Income (simulated) (in million dong)	15.2	9.1	7.2
Prob (income< 8m)	0.08	0.318	0.154
Mean stocking rate (PL/m^2)	1.15	0.31	0.72
Income at mean shrimp yield, stock = 2 million dong	19.0	16.0	15.0

Effect of credit

An alternative means of financing stocking when cash funds are low is to borrow. The effect of credit is illustrated by comparing simulated income distributions for cases with and without credit. For the credit scenarios it is assumed that there is a limit of 4 million dong on the amount that can be borrowed (average loan size observed in the survey), and two lending rates are examined. One represents the cost of formal credit, at 1.5% per month; the other represents the cost of informal credit, which is around 6% per month.

Incomes were calculated for the most and least diversified farm in My Xuyen, and results are summarised in Table 5. The results for the most diversified farm showed little difference between credit scenarios, largely because this farm rarely had to rely on credit to finance stocking. In contrast, the availability and cost of credit affected the probability distribution of income for the least diversified farm, as it is more dependent on credit to finance stocking. The probability distributions for the least diversified farm under different credit assumptions are shown in Figure 6. The leftwards movement of the probability distribution as credit is removed (formal

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

versus no credit) is due to the effect being less able to finance stocking, and implies that the farmer is worse off if formal credit is not available. In contrast, the high cost of informal credit results in the farmer being worse off than if credit is not available. This is because the pay-off from borrowing to invest in shrimp does not cover the high interest cost.

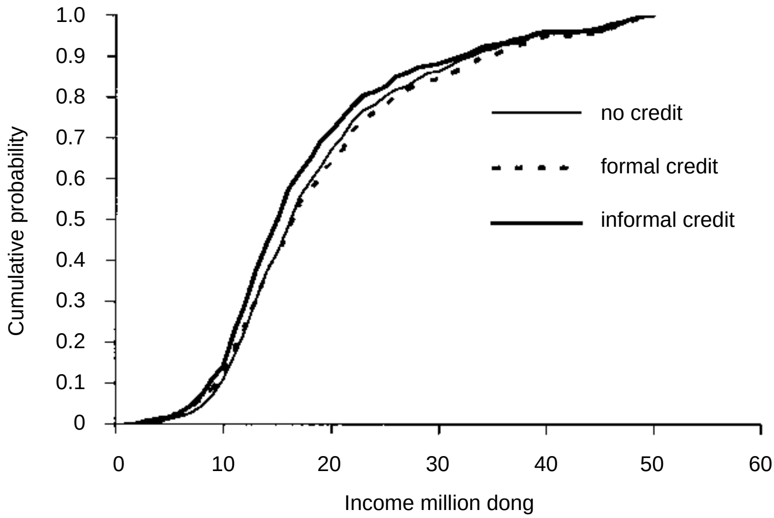

Figure 6. Probability distribution of income for different credit scenarios: poorly diversified My Xuyen farm.

Table 5. Effect of credit on income and stocking for My Xuyen.

	No credit	Formal	Informal
Well diversified			
Mean income (in million dong)	16.82	16.9	16.87
Mean loan size (in million dong)		0.233	0.245
Mean stocked	1.94	1.99	1.99
Frequency that stocking < 2 PL/m^2	0.13	0.007	0.008
Least diversified			
Mean income (in million dong)	8.43	8.62	7.81
Mean loan size (in million dong)		2.127	2.141
Mean stocked	1.18	1.30	1.15
Frequency that stocking < 2 PL/m^2	0.742	0.632	0.723

Results in Table 5 show that access to formal credit improves income for the My Xuyen case, though the impact is much greater when other sources of farm income are limited. In the case of the least diversified farm, the farmer is better off not using credit if it is only available at the informal rate of 6% per month. In contrast, the well-diversified farm is slightly better off adopting the (infrequently demanded) informal credit sector if formal credit is not available.

Results for the Gia Rai case, shown in Table 6, are not very pronounced, although some interesting conclusions can be drawn. For each farm type, the best strategy is to avoid borrowing

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

money for financing shrimp production — even at formal credit rates. This is because the higher riskiness and lower yield in Gia Rai mean that the cost of credit is not worth the return on stocking.

Table 6. Effect of credit on income and stocking for Gia Rai.

	No credit	Formal	Informal
Well diversified			
Mean income	10.46	10.45	10.40
Mean loan size	0	0.215	0.273
Mean stocked	1.95	2	2
Frequency that stocking < 2 PL/m^2	0.264	0	0
Least diversified			
Mean Income	5.00	4.92	4.60
Mean Loan size		1.494	1.323
Mean Stocked	0.70	0.72	0.62
Frequency that stocking < 2 PL/m^2	0.925	0.915	0.933

Monodon production under quarantining strategies

Shrimp virologists suggest that farmers should try to remove all potential sources of pathogens from their monodon shrimp ponds, and in many production systems farmers use fences to prevent crabs from getting into their ponds (Walker 1999). However, it is common practice on rice–shrimp farms, particularly in Gia Rai, to culture other types of crustaceans, including crab and naturally recruited shrimp species. Evidence from the household survey indicates that monodon and natural shrimp are often stocked in the same pond, and stocking of crabs in ponds adjacent to monodon has also been observed.

As demonstrated in previous sections, opportunities to earn alternative sources of income provide an insurance against the risk associated with monodon stocking. Thus, recommendations regarding 'quarantining' of monodon ponds provide a dilemma for the farmer. While the removal of other species may increase monodon survival, it also takes away 'income insurance' in the event of poor monodon performance. Since it is not possible to predict accurately to what extent the survival of monodon would be improved, it is unclear whether the farmer would be better off by concentrating on monodon culture.

The trade-off associated with giving up the practice of multi-species production is illustrated in Figure 7. Three curves are shown, one reflecting the current experience in Gia Rai (for a well-diversified farmer) and the other two representing the income that would be realised if the farmer focused solely on monodon production. These figures are based on a stocking rate of 1 PL/m^2, which is typical of Gia Rai farms. The two alternatives demonstrate two possible yield outcomes, ranging from one that is based on the currently observed survival, and the other based on the probability distribution of survival that has been observed in My Xuyen, where it is uncommon to culture other crustaceans when monodon is being stocked. These two scenarios could represent the range of outcomes that the farmer might perceive to result from adopting single species production. The worst case scenario is that survival would not be affected — in which case the farmer is definitely worse off by giving up the multi-species system. In the better

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

scenario, where survival is improved to the level experienced in My Xuyen, the farmer may still not be better off, especially if he is risk averse, because the resulting income distribution is more spread. These results highlight the non-trivial nature of the trade-off associated with changing away from the current mixed-species stocking practice.

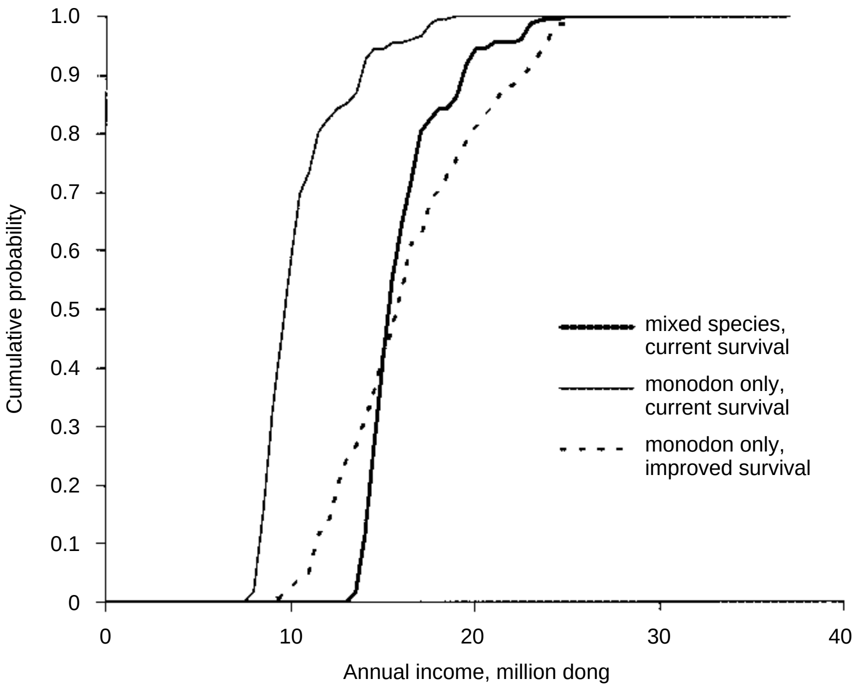

Figure 7. Comparing risk under disease-quarantining strategies.

Banana shrimp as an alternative species

The focus of this research project has been on the two shrimp-stocking strategies that predominate in the region: artificially stocked monodon production and naturally recruited native species. The natural recruitment method has been shown to be unsustainable because of the sedimentation that occurs (Clayton this Report). The monodon system is more promising and has potential to provide good economic returns in My Xuyen where survival is better. However, the high cost of monodon postlarvae mean that the farmer must have significant capital at the beginning of the season to finance investment in seedstock. This money is lost if the shrimp do not survive. The risks presented by the possibility of poor harvests highlight the need for sufficient capital or other sources of income for farmers in order to manage risky income flow.

One option that might be considered as an alternative species for artificial stocking is banana shrimp (*Penaeus merguiensus* and *P. indicus*). This species is being grown by a minority of farmers at present. One of the advantages of banana shrimp is that it is much cheaper to buy because the species is locally abundant and because it is easier to spawn. Compared to monodon which costs 100–200 dong per postlarvae, banana shrimp can be purchased for around 50 dong per postlarvae. However, a disadvantage is that the banana shrimp don't grow to the same size as monodon, and

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

therefore the yield (for a given survival rate) is lower, as is the price per kilo because of the premium paid for larger shrimp.

The returns from investing in banana shrimp are compared with monodon in Figure 9. These calculations were based on an assumed growth rate for banana shrimp which is illustrated in Figure 8. Banana shrimp growth rates are based on evidence from recent on-farm trials in Australia, which indicated that banana shrimp grow at the same rate as monodon up to about 13–14 g, after which growth plateaus significantly (Nigel Preston, personal communication 1999). The growth rate of the plateau section of the growth curve is estimated to be about 1 gram per week, but a slower growth rate of 0.5 gram per week, as illustrated in Figure 7, is also examined here.

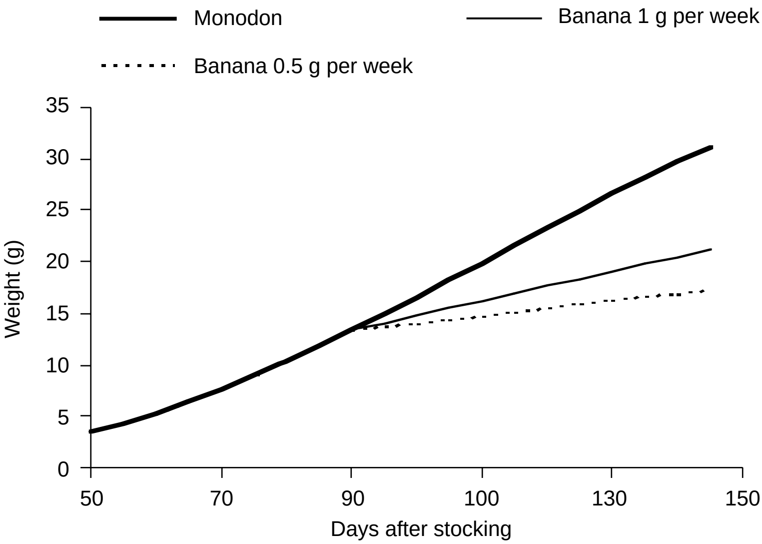

Figure 8. Banana shrimp growth model.

Results are shown in Figure 9 for these two growth rates, under an assumed stocking rate of one postlarvae per square metre. The figure illustrates that income that would be earned as a function of total shrimp-stocking time. When time is less than 80, the shrimp are not a marketable size, so the net income from harvesting at a day prior to 80 is simply the loss associated with stocking costs incurred up to that date. Beyond 80 days, the farmer can sell the shrimp, but the income from sale increases as the total shrimp-stocking time increases. This is due to both higher biomass and higher price per kilo as shrimp reach a larger size. It can be seen that if shrimp are harvested prior to about 105 days, the farmer makes more money out of banana shrimp than out of monodon. This is because the shrimp growth rates are comparable at early stages of production and because the cost of stocking banana shrimp is much lower. As the harvest date is extended beyond 105 days, the benefits from monodon production start to be realised. These benefits occur because the much higher growth rates and resulting revenue more than justify the higher stocking costs.

The implication of these results is that if an early harvest date is anticipated, the farmer is better off growing banana shrimp species. Since early (emergency) harvesting is often undertaken by farmers when there is a known outbreak of white spot in neighbouring areas, expected crop

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

length may not always be long enough to justify monodon stocking. Moreover, because stocking is cheaper for banana shrimp, losses are lower in the event of crop failure.

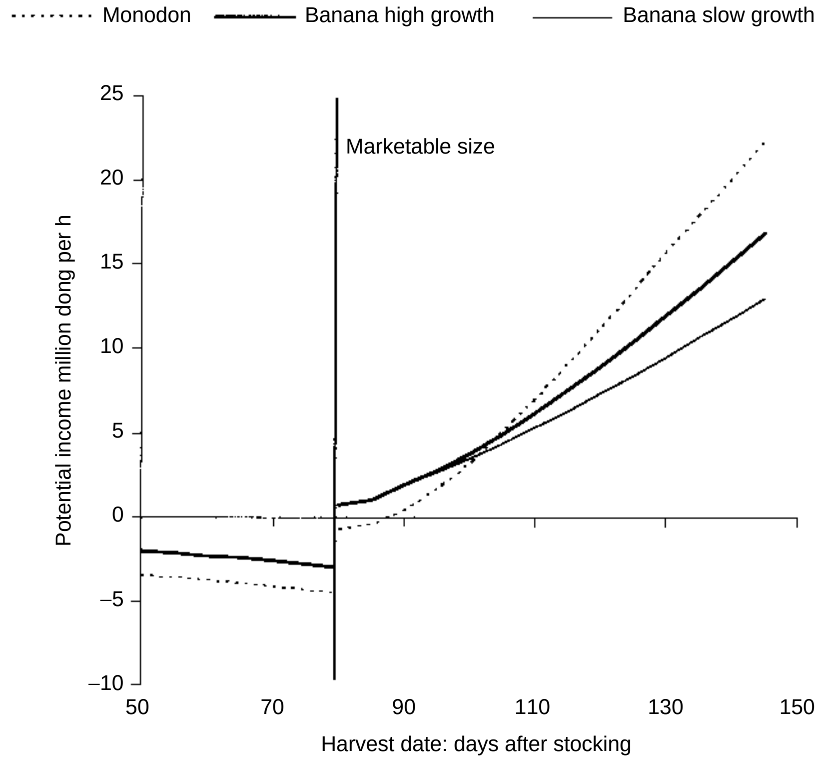

Figure 9. Comparison of income from banana shrimp and monodon.

Conclusion

The analysis in this paper demonstrates the risky nature of shrimp production and some of the strategies that might be used to reduce income risk. The multiplicative nature of risk means that farm income risk is directly related to stocking density. While the per-farm payoff to good survival is high when farmers stock more intensively, the downside risk is also much larger at higher stocking rates. Farmers that are risk averse, or those that are constrained by low cash reserves, are more likely to stock at lower stocking densities. However, the converse is that, as farmers become more wealthy and are less constrained by cash availability, they may start to intensify their stocking. This phenomena has been observed already in My Xuyen — over the course of the research project field workers have reported that farmers are tending to increase their stocking rates. A higher stocking density is of concern to policy makers because of the potential environmental consequences.

The importance of a diversified farm household income as a means of managing shrimp income risk was also demonstrated here. An advantage of the rice–shrimp farming system is that income diversification is a natural consequence of the system — the seasonal nature of production results in idle land and/or labour that can be used to earn income from other sources,

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

including agricultural and off-farm income. The rice production results in a staple food supply in the event of a poor shrimp crop. This in-kind income is less likely to be 'gambled away' in shrimp production, providing food security for the household.

The analysis showed how the cost of credit and the expected survival of shrimp are critical in determining whether or not farmers should use credit to source shrimp postlarvae. If shrimp survival is expected to be as good as has been observed in My Xuyen, then the expected return from shrimp stocking is high enough to justify using credit, even at informal credit rates. However, if shrimp survival is as poor as it is in Gia Rai, then farmers are better off not borrowing money to stock, even if they can access the cheaper formal credit.

The importance of farm income diversification as a means of managing risk implies that farmers may not be willing to adopt the 'quarantining' strategies that have been recommended in other shrimp-producing regions. This may create difficulties in coming years as the technology for producing pathogen-free postlarvae reaches the Mekong Delta. Those farmers that are able to access pathogen-free stock are likely to want to follow a 'monodon only' stocking strategy, while their poorer neighbours may wish to cultivate mixed species systems, thus providing an unwanted potential viral source to their neighbours' ponds.

Finally, it should be noted that as long as it remains difficult to source an adequate supply of high health monodon postlarvae, it might be worthwhile investing research funds into alternative species. The analysis of banana shrimp presented here indicates that in some situations banana shrimp may be a better investment than monodon.

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Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 11

Bioeconomic factors in sedimentation related land loss in the natural rice–shrimp system

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I would like to acknowledge the research contribution from Donna Brennan and Tran Thanh Be in the development and analysis of the conceptual and empirical model presented in this paper — Helena Clayton

Abstract

This paper is concerned with land degradation in the rice–shrimp system arising from the loss of land from the build up of sediment over time. The land loss is primarily associated with systems reliant on high water exchange for natural recruitment of shrimp seed. Alternative low land-degrading (low water-exchange) rice–shrimp technology is available in the Mekong Delta; however, the high capital outlay and risks associated with such technology may constrain the ability for poorer farmers to adopt it. The aim of the paper was to evaluate the economic implications of the land loss and explore some of the economic factors that might explain why it has occurred. A bioeconomic spreadsheet-based model was developed to evaluate the net benefits of alternative production scenarios which have different implications for land loss. The net benefits of the alternative scenarios were simulated under different assumptions about time preference and farm planning horizons. The results indicate that there are limited incentives for natural rice–shrimp farmers to move away from production choices that lead to land loss. The economic dimensions of this result were discussed in the paper with reference to technological change, policy and farm extension implications.

THE LAND LOSS arising from sedimentation in rice–shrimp systems is the subject of this paper. The loss of productive land primarily arises in systems reliant on tidal recruitment of natural shrimp rather than the systems based on stocking of hatchery-purchased postlarvae.[2] This is because tidal recruitment requires high-water exchange rates. The frequency of water exchange is a significant factor in land loss as it is through the exchange and inundation of turbid water throughout the shrimp-raising season that suspended sediment settles to the floor of the rice–shrimp polder. The bioeconomic dimensions of the resultant land loss arising from such sedimentation are described in the following section. Throughout this paper, rice–shrimp systems based on tidal recruitment of natural shrimp are referred to as the 'natural rice–shrimp system'.

While the natural rice–shrimp system has provided households in the Mekong Delta with low-input and low-risk opportunities for increasing income and accumulating capital over time, the growing scale of land loss raises questions about the long-term sustainability of the system. This paper:

- investigates the economic nature of land loss in the natural rice–shrimp system and explores the relevant economic policy issues;

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[2] See Chapter 1 (this Report) for an overview of the different rice–shrimp systems in the Mekong Delta

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

- evaluate the relative economic benefits of alternative rice–shrimp production choices from private and social perspectives;
- discusses the economic aspects of land loss in relation to technological change.

A bioeconomic model was developed which describes the process of sedimentation in the natural rice–shrimp system and links decisions about water exchange to the implications of those decisions for long-term land loss and income.

Bioeconomic dimensions of land loss in the natural system

A simple representation of the bioeconomic dimensions of losses in projective land area in the natural rice–shrimp system is illustrated in Figure 1.

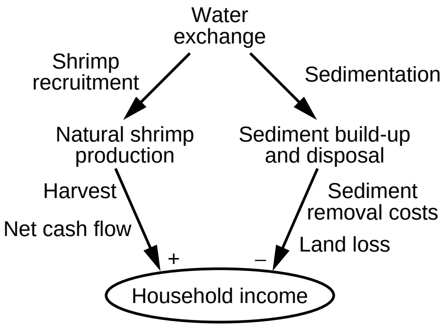

Figure 1. Components of the natural shrimp production system under land degradation.

The decision variable of most interest is water exchange because of the intertemporal trade-off between current water-exchange decisions and subsequent land loss. As illustrated in Figure 1, water exchange decisions are linked to household income in two main ways. First, shrimp postlarvae are recruited into the pond via the exchange of water and are later harvested for sale at local markets or kept for home consumption. Second, water brought into the pond also brings in sediment which, over time, builds up on the polder floor.

The build-up of sediment throughout the shrimp production cycle in the already shallow rice–shrimp polder needs to be removed at least once per year to maintain a pond depth necessary for a healthy pond environment for shrimp. The sediment is generally disposed of within the farm boundary, either around the house, on vegetable plots or on top of the dikes bordering the rice–shrimp field. However, once these areas reach their capacity, new mounds are created within the rice field for the sole purpose of sediment disposal. Over many years the sediment mounds take up space on land that could otherwise be used for production. The physical process of land loss arising from sedimentation is shown below in a cross-sectional illustration of the rice–shrimp polder (Fig. 2).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

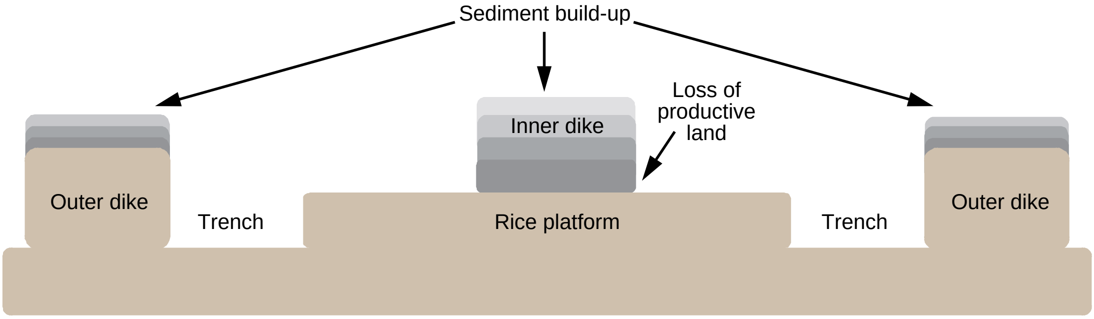

Figure 2. The process of sedimentation and land loss over time.

Cross-sectional data on temporal changes in dike area are very difficult to obtain because the demand on farmer's recall memory is high due to the complexity of the rice–shrimp polder design. For example, the design of the polder in some cases incorporates a sedimentation pond, several different polders and several polder design changes over time. Despite the difficulties experienced in primary farm data collection, the ACIAR farm surveys and related fieldwork indicate that sedimentation and the associated land loss varies substantially across the ACIAR study region but is a significant problem for many farmers. Land loss has been found to be most severe in Gia Rai, where natural recruitment practices dominate and where shrimp farming has been practised the longest.

The natural rice–shrimp farm model

The model presented below consists of a series of equations that describe the bioeconomic relationships inherent in the natural rice–shrimp system under land loss. The empirical model was set up in spreadsheets. The relationships and parameter values are based on the ACIAR farm data, expert opinion and relevant scientific studies. Land loss was simulated for two discrete water-exchange scenarios, namely low and high water exchange. These two scenarios represent different rates of sedimentation and imply differences in the trade-off between current and future income.

Net economic benefit

The net economic benefits from natural rice–shrimp production were evaluated over time, which means that there is a need to account for time preference. Time preference is the basic concept that outcomes (benefits and costs) in the current period have greater importance compared to those in the distant future. Discounting is the standard way in which time preference is dealt with in economics. A specified rate of discount is applied to calculate the 'present value' of a stream of net benefits accruing over time. The sum of discounted net benefits is the net present value (NPV), calculated using the following formula (Equation 1).

$$NPV = \sum_{t}^{T} \frac{y_t}{(1+r)^t} \qquad (1)$$

where:
T is the planning horizon
t represents one year
y_t is annual income in year t
r is the rate at which future income is discounted (the rate of time preference).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

The rate of discount (r) and time horizon (T) are important economic factors when analysing the economics of sustainability.

Income

The annual net cash income per hectare for the natural rice–shrimp production system is described in Equation 2a.

$$Y_t = P_r.Q_{rt} + P_s.Q_{st} - a.A_t - f.F_t - O_{vt} - FC \quad (2a)$$

where:
Y_t is annual net cash income in year t
P_r is the harvest price for rice
Q_{rt} is the annual rice yield in year t
P_s is the harvest price for natural shrimp
Q_{st} is the annual natural shrimp yield in year t (see Equation 5)
A is the hours hired for sediment removal in year t; a is the cost per unit
F is the quantity of shrimp feed in year t; f is the price per unit
O_v is sum of other variable costs in year t
FC is other costs which are fixed, such as basic polder maintenance.

Annual natural shrimp income (Y_{st}) under land loss is expressed in Equation 2b.

$$Y_{st} = f(X, L_t) \quad (2b)$$

Equation 2b is a simple representation of the income trade-off over time under land degradation. The equation represents natural shrimp income as a function of water exchange (X) and productive land area (L). The income from natural shrimp is a positive function of water exchange through natural shrimp recruitment. Land area is a negative function of water exchange through sediment build-up over time. More detail on yield and sedimentation relationships is provided in the sections following.

Build-up of sediment

The total sediment 'load' in the polder over an annual production cycle is described in Equation 3 (adapted from Equation 8 in Brennan and Clayton 1999, p. 12):

$$Z = \frac{\left(V_0 + \sum_{m}^{12} X_m\right).T}{1000} \quad (3)$$

where:
Z is the annual sediment load (kg)
V_0 is the pond volume at the start of the year (m^3)
X is the volume of water exchanged per month (m^3)
T is the net density of suspended solids per volume of water (g/m^3), which is the TSS in the intake water minus TSS in the out take water
m represents one month.

The total volume of the accumulated sediment in year t is expressed by Equation 4.

$$\eta = \sum_{t}^{Y} Z/d \quad (4)$$

where:
η is the volume of accumulated sediment in year t (m^3)
Z is the sediment load per year (kg) (from Equation 3)
d is the density of dry sediment (kg/m^3).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

The density of the dry sediment in the dike (d, kg/m^3) is based on assumptions about the bulk density of the 100% dry sediment (g/m^3) and the moisture content of the dike dry sediment.

Land loss over time

The translation of the volume of accumulated sediment to loss of land area (area of inner dike) requires a number of assumptions to be made about polder dimensions, outer-dike capacity and inner-dike dimensions. Based on the ACIAR survey data, the original rice–shrimp polder dimensions (at t_0) are assumed to be 0% inner dike, 8% outer dike area, 14% trench area and 78% field area.

As sediment accumulates over time it is assumed in the model that the outer dike capacity is exhausted first. Once this is exhausted, the construction of inner dikes is required. The outer dike dimensions at t_0 are assumed to be 0.5 m high by 1 m wide, and it is assumed that the maximum height possible for the outer dike is 1 metre. Thus, initially the capacity (space available) of the outer dike (per hectare) for the deposition of accumulated sediment is (1 m–0.5 m).800 m^2 (i.e. 800 m^2 is 8% of one hectare).

Based on farm observations, the inner dike dimensions on the field are assumed to be 1 m in height by 1.5 m wide. Hence, for each cubic metre of sediment accumulated (once the outer dike capacity has been exhausted), two thirds of a metre of the field length is consumed. Therefore, the total area taken up per cubic metre of sediment is 1 m^2 (1.5 m wide by 0.66 m field length).

Natural shrimp yield

The natural shrimp yield is expressed in Equation 5.

$$Q_s = (c_1 X_i - c_2 X_o).\delta.w \qquad (5)$$

where:

c_1 and c_2 are the density of shrimp juveniles per volume of intake and out take water, respectively c_2 are the 'escapee' postlarvae

X_i and X_o refer to the volume of intake and out take water, respectively

δ is the survival rate of shrimp

w is average harvest weight of shrimp.

Water exchange scenarios

Two model scenarios were developed for the purpose of exploring the economic incentives for reduced water exchange in the natural rice–shrimp system. The two scenarios — low and high water exchange — are outlined below. These scenarios are based on data of natural shrimp recruitment from a study of mangrove–shrimp systems in Ca Mau Province in the Mekong Delta (Johnston et al. 2000).

Low water-exchange scenario

The low-exchange scenario represents a shrimp recruitment regime concentrated in months of the year that coincide with peak postlarvae densities in the rivers and canals. The periods of the year found to have the highest postlarvae recruitment in the mangrove–shrimp systems were October–November and April–May (Johnston et al. 2000).

The rationale behind this scenario is that the trade-off between recruitment and sedimentation can be reduced by practising high water exchange in the peak periods and low or zero exchange when postlarvae are more scarce. Based on farmer information collected in the

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

project, there is evidence that some farmers are aware of seasonal fluctuations in seed stock densities throughout the year and do alter their recruitment accordingly.

The frequency of water exchange throughout the year for this scenario is presented in Table 1.

Table 1. The low water-exchange scenario: water-exchange frequency throughout the year.

	Water exchange decisions			
	Days per month	Times per day	Times per month	Months
March	2	1	2	1
April–May	4	1	4	2
Oct–Nov	6	4	24	2

In Figure 3 the water-exchange rates specified for this scenario are combined with recruitment density data (number of postlarvae per cubic metre of water) from the mangrove–shrimp study.

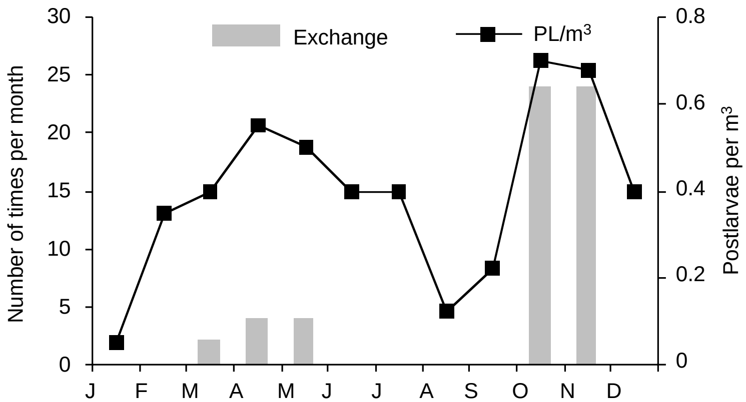

Figure 3. Water-exchange and recruitment densities in the low-exchange scenario.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

High water-exchange scenario

In the high-exchange scenario, farmers opt to exchange water as frequently as possible. The recruitment regime in this scenario is similar to that observed in the ACIAR survey for the sub-sample of farmers who raise only natural shrimp in both dry and wet seasons. In this scenario, water is exchanged at each spring tide for ten days over ten months of the year. During the months of November and December, farmers are assumed to carry out polder reconstruction and therefore do not recruit shrimp, common practice for farmers interviewed in the ACIAR survey. In Figure 4 the water-exchange frequencies are again combined with the shrimp-density data.

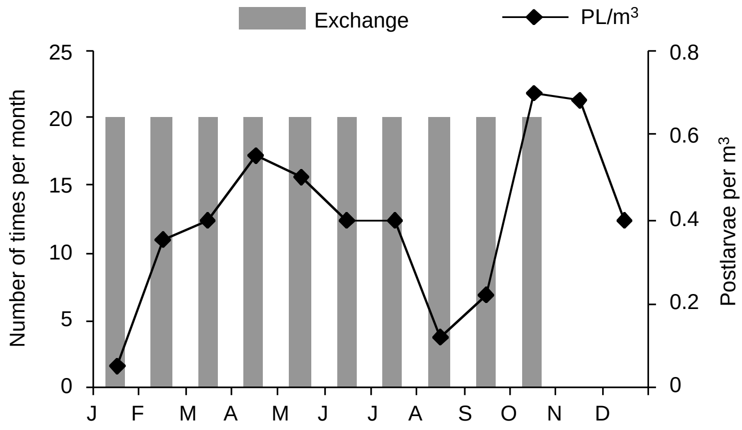

Figure 4. High water-exchange scenario.

Model assumptions

The assumed parameter values for the model are outlined in the table and notes overleaf (Table 2). These assumptions are based on data from the ACIAR farm survey (Brennan et al. 1999). The opportunity cost of family labour is included in the relevant variable costs, valued at the market rate for labour (25 000 dong per day), which is reflective of foregone off-farm employment.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 2. Assumptions.

	Assumption value		Note
Sedimentation assumptions			
Net TSS (g/m^3)	250		1
Bulk density (g/cm^3)	1.5		2
Moisture content of dike	30%		2
Shrimp assumptions			
Water exchange scenario	*Low*	*High*	
Exchange (months per year)	5	10	
Exchange (days per year)	60	200	
Measure of water exchanged per time (m)	0.27	0.27	3
Shrimp recruitment density (PL/m^3)	0.66	0.37	4 & 5
Shrimp survival (%)	0.3	0.3	6
PL loss (%)	0.4	0.4	7
Harvest weight (grams)	10	10	8
Sediment removal cost ('000 dong/ha)	925	1667	9
Feed costs ('000 dong/ha)	0	0	10
Fixed costs ('000 dong/ha)	717	717	11
Price ('000 dong/kg)	22.87	22.87	12
Rice assumptions			
Yield (year t_0) (t/ha)	4000		13
RS penalty (%)	6		14
Subsistence consumption (kg)	1400		15
Variable costs ('000 dong/ha)	1925		16
Price ('000 dog/kg)	1.6		17

Notes

1. The density of TSS in intake water was measured using a data-logger positioned at the site of an experimental farm in My Xuyen in 1998 (ACIAR project data).
2. These assumptions are based on expert opinion (Riko Hashimoto, personal communication, 2000[3]).
3. This is based on farmers' estimates of the height of water exchanged per exchange period. The 0.27 metres assumption is the average from the 1997 ACIAR farm survey data. The volumetric measure of water exchange is the height of water exchanged multiplied by the pond area. The total volume of water exchanged per year is calculated as the number of metres exchanged per year multiplied by the polder area.
4. Recruitment data from Johnston et al. (2000) were used. The weighted average (0.66 PL/m^3) was calculated based on the low-exchange scenario. The net recruitment density per unit of water exchange after accounting for recruitment losses and shrimp survival rate is 0.12 PL/m^3.
5. Again recruitment data from Johnston et al. (2000) were used. The average density of postlarvae density from January–October (0.369 PL/m^3) was applied. The net recruitment density per unit of water exchange after accounting for recruitment losses and shrimp survival was 0.066 PL/m^3.
6. Evidence on natural shrimp survival is sparse because of the difficulties in data collection. Therefore, the assumption of 30% was based on average survival rates in *Penaeus monodon* systems in My Xuyen.
7. This assumption is based on sampling reported in Johnston et al. (2000) during harvests (ebb tides) in order to measure losses of shrimp juveniles in the harvesting process.

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[3] Riko Hashimoto, PhD candidate in School of Geosciences, University of Sydney.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

8. The weight assumption is based on expert opinion (Tran Than Be and Le Xuan Sinh, personal communication, 2001[4]) and is consistent with the ACIAR data on shrimp prices against shrimp size.
9. Sediment removal cost based on average costs from ACIAR survey. In the low-exchange scenario, sediment costs are based on subset of farmers with only one season of natural shrimp production. In the high-exchange scenario, costs are based on subset of farmers recruiting natural shrimp only, in both the wet and dry seasons.
10. Zero feed cost assumption is supported by the ACIAR survey data that show limited or zero feeding for natural shrimp production.
11. Fixed costs are based on the polder preparation cost data from the 1997 survey (not including costs associated with sediment removal).
12. Average harvest price based on 3-year ACIAR survey data.
13. Average rice yield in rice monoculture crops, 1997 ACIAR data.
14. The penalty is based on reduced yields arising from delayed planting that occurs in the rice–shrimp system to allow for the flushing of salinity from the soil at the beginning of the wet season.
15. Average, 1997 ACIAR data.
16. Average, 1997 ACIAR data.
17. Average, 1997 ACIAR data.

Projected land loss over time

The projected land loss (represented as increased dike area) for the low and high water-exchange scenarios under the base-line assumptions (Table 2) are shown in Figure 5.

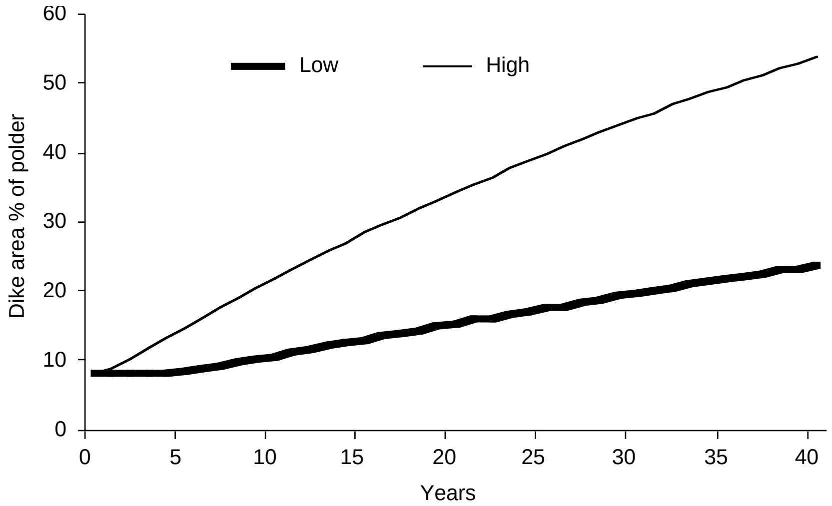

Figure 5. Projected increase in dike area over time.

In the low-exchange scenario, the outer-dike capacity for sediment disposal is exhausted after eight years. The model simulates construction of inner dikes for deposition of continued sediment accumulation after the exhaustion of the outer dike. In the high-exchange scenario, the outer-dike capacity is exhausted within the first few years, which means that the onset of land loss begins within the first two years of natural shrimp production. Over time, in both cases, as more and more field area is taken up with inner sedimentation dikes, the pond capacity is reduced. The loss of land occurs at a decreasing rate because the rate of sediment accumulation slows with the declining pond water area. This is reflected in the 'curving-off' of the curves over time (seen

[4] Informal discussion, University of Sydney.

in Fig. 5). The empirical evidence available on dike-area increase supports the model-projected land loss in that the projections lie within the range of land loss experienced by many rice–shrimp farmers in the survey region.

Validating projected natural shrimp yields

Before the results in terms of projected income are presented, a brief discussion is provided on the validity of projected natural-shrimp yields. In Table 3 the observed and model-projected natural shrimp yields are shown. The observed yields shown in the table are the average Gia Rai yields from the 1997 ACIAR data. Gia Rai data were used as this is the district where natural-shrimp production is most commonly practised. The farm data were summarised according to farming system data groups to provide a consistent match with the projected yield based on the model scenarios. Group A (low water exchange) includes data from a subset of farmers who limited their natural shrimp production to only one season (either the wet or dry season) and also raised *P. monodon* species. The subset of farmers that make up Group B (high exchange) targeted natural shrimp as a primary activity in both the dry and wet season, which meant that their water exchange tended to be relatively high.

Table 3. Natural shrimp yield, observed and projected, for high and low water-exchange groups.

Water Exchange	Observed NS yield (kg/ha)	Projected NS yield (kg/ha)		
		Survival 30%	Survival 20%	Survival 10%
Farm group A: Low water exchange	189[a]	177	118	59
Farm group B: High water exchange	263[b]	289	193	96

[a,b] Significant difference between groups (P=0.000)

The projected yields are shown in the table for assumed survival rates of 30%, 20% and 10%. Under the 30% survival rate, the model is shown to be a good predictor of the natural-shrimp yield.

Projected income over time

The projected non-discounted net income streams for the low and high water-exchange scenarios are compared in Figure 6. The high-exchange system generates relatively high income in the short-term, but the substantial trade-off arising from the quick decline in pond capacity over time is shown by the relatively steep negative slope. Within 35 years, annual income under low exchange begins to exceed the high-exchange system. The results here illustrate the unsustainable trend associated with the high water exchange.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

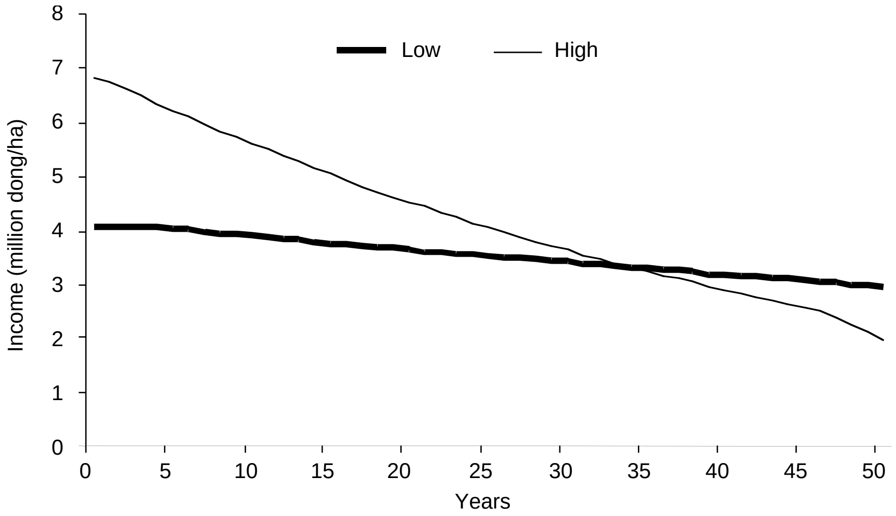

Figure 6. Net annual income projections (no discounting).

In the next section the net present value (NPV) of the income streams shown in Figure 6 are evaluated at different points in time, under different rates of time preference representative of private and social perspectives.

Relative net present value

The discounted income streams shown in Figure 6 were evaluated at 20-, 40- and 60-year time horizons. Two discount rates were applied — a high discount rate of 20% was applied as a representation of shortsighted private decisions and a low discount rate of 5% was applied as a representation of 'sustainability' or social preferences.

The relative NPV for the low and high water-exchange scenarios is illustrated here by way of an NPV ratio expressed as NPV_{low}/NPV_{high}. The two scenarios of low and high water exchange represent low-degrading and high-degrading systems, respectively; therefore, the circumstances under which the NPV ratio is greater than one is of particular interest as this is when the net benefits from the more sustainable low-exchange scenario outweigh those of the high-degrading system. The sensitivity of the NPV ratio to farm-planning horizon and the rate of discount is explored in the model evaluations.

The NPV ratios are shown in the histogram in Figure 7. The advantage of the high-degrading system is the possibility of relatively high returns in the early years of production. However, the cost of the high returns is a loss of land in the future. Under high discount rates, the value of future income becomes negligible relative to income earned in the present or near future; therefore, it is not surprising that the high-exchange scenario dominates under private time-preference rates. In fact the NPV ratio is less than one under all discount rates and planning horizons.

Long planning horizons and low time-preference rates have the effect of increasing the relative value of the low-exchange system; however, the results indicate that the higher early returns possible under the high-exchange scenario are large enough to outweigh the reduced income over

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

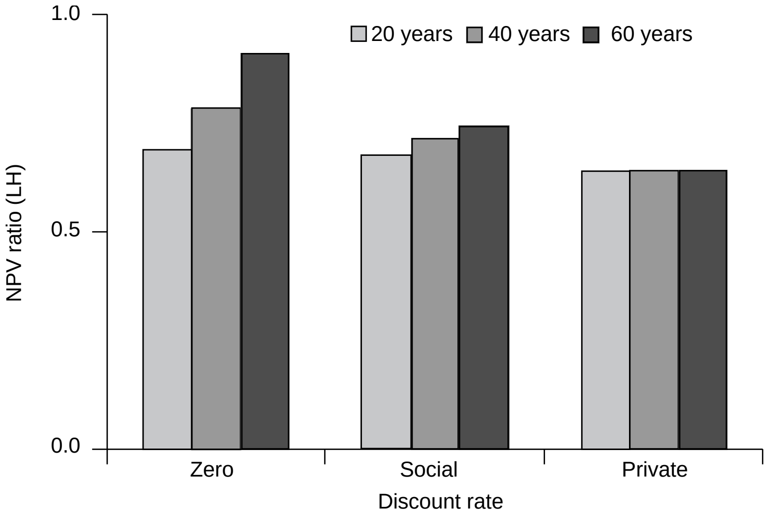

Figure 7. NPV Ratio (L:H) over different planning horizons and discount rates.

time from the high rate of land loss[5]. The NPV ratio increases in favour of the low-exchange option the longer the period over which the system is evaluated, and as expected, the NPV ratio is lowest under the private time-preference rate.

In the high-exchange scenario, although it is predicted that within 60 years farmers would experience a loss of around two thirds of their productive land area, the results also show that there is no economic incentive for farmers to reduce their water exchange in the natural-shrimp production system. This is the case both from a private and social perspective. The difficulty in this land degradation problem is that water exchange is, at the same time, a culprit behind the land degradation and the main source of income from the system. The observed high rates of land loss in parts of the study region support the results from the model that indicate that there are limited incentives for farmers to practise low water exchange in the natural rice–shrimp system.

An important assumption behind the results is that farmers' decision making does not incorporate the option of adopting new technology over the planning period. It is, however, foreseeable over a 60-year time horizon that farmers could adapt their farming technology in response to changing economic and environmental conditions. There are several socioeconomic factors that would help or hinder adaptation and adoption of alternative technology. For example, income level, credit availability, risk and access to farm extension are all important influences in technology adoption by farmers. Farmers' adaptation and adoption of alternative technology is discussed in the following section with reference to the static representation of technology assumed in the model of the natural rice–shrimp system that has been presented.

[5] Note that this is the case even when discount rates are zero

Alternative rice–shrimp technology and land loss

In some cases a static representation of technology may be an appropriate and realistic representation of the land degradation problem. However, in other cases a static view of farm technology misrepresents the dynamic nature of rural development in which new technology can emerge as a result of farm-based trial and error, research and farm extension.

Currently in the project study area, some farmers have adopted rice–shrimp systems based on hatchery stocking of *P. monodon* shrimp rather than tidal recruitment of natural shrimp. It has been through farmers' trial-and-error, local extension activity and research activity of local universities and government departments in the Mekong Delta that *P. monodon* rice–shrimp technology has become a production option for farmers. This alternative technology has some advantages in the context of land loss because the system does not require high rates of water exchange; however, the practice of *P. monodon* rice–shrimp systems in the Delta has not been without its own sustainability problems. Uncertain and low shrimp survival is a problem of crucial concern with *P. monodon* technology because of the effects that risky survival can have on economic viability and farm income risk (see Brennan this Report).

In Clayton (2002), the net benefits of the high water-exchange scenario and the *P. monodon*-based system were compared. The results challenge the conclusions drawn from the analysis of land loss under a scenario of no technological change. With the introduction of alternative technology into the analysis, the high land-degrading scenario was found not to dominate under all circumstances. However, survival rates of at least 30% were found to be necessary for *P. monodon* to become an economically feasible option for farmers currently practising the high water exchange rice–shrimp system. This result suggests that, to the extent that the technological environment is dynamic and adoption of low-risk and good-survival *P. monodon* technology is possible, the long-run opportunity costs of land loss are underestimated under a static representation of technological change.

The results in Clayton (2002) indicate that there are potentially significant social benefits to be gained from research and farm extension that work toward achieving high and stable *P. monodon* survival. Further discussion of the opportunities and constraints associated with the *P. monodon* rice–shrimp system is provided in a discussion of the policy implications below.

Policy implications and conclusions

Under the implicit assumption that farmers do not have access to alternative production options, it was concluded that the high-exchange (high-degrading) system, is preferred under both short- and long-term evaluations. This was an expected result for the evaluation under short time horizons and private discount rates. However, based on long time horizons (60 years) and low discount rates (zero and 5%) these results were contrary to expectations. Nevertheless, the results suggest that the apparent problem of land degradation is not a social problem, and hence there is not sufficient justification for policy or institutional intervention.

Despite these conclusions, the land degradation observed in the study area remains a concern for local and provincial government officers and local farmers. The results from extended analysis reported on in this paper which incorporated alternative *P. monodon* technology suggests that there is a situation where it is socially and privately optimal not to degrade the land. The survival rates of *P. monodon*, however, are pivotal in this, as under low survival rates the high-degrading natural-shrimp system remains economically favourable from both private and social

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

perspectives. The shrimp survival rate continues to be one of the most contentious and difficult factors in the sustainability of *P. monodon*-based technology.

The survival rates of *P. monodon* in the Gia Rai District are particularly low. Based on the results discussed in this paper, it is not surprising that the continued practice of the natural rice–shrimp system (i.e. the static view of technological change) is observed despite the land loss problems encountered with sedimentation. To the extent that there is potential for survival to improve in the longer term through technological and institutional development, the analysis does indicate that 'market failure' is likely to be a problem. Therefore, there is a case for public investment into achieving improved shrimp survival. This will provide improved access for farmers to economically sensible alternative rice–shrimp technology.

Credit policy is another area of concern in relation to the accessibility of alternative technology. Even if improved *P. monodon* technology (higher survival) were available, the poorly functioning formal credit market in the Delta presents constraints for natural rice–shrimp farmers in adopting the alternative technology. Improved access to formal credit for rice–shrimp farmers has been an important policy consideration of the provincial and district Departments of Agriculture and Rural Development in the study area.

Credit policy, however, is a complex policy area because of concerns about risk and farm indebtedness. In local credit policy in the study area, there is an expectation that loans be provided to rice–shrimp farmers only as supplementary capital. The rationale for this is in part to limit the risk exposure of farmers raising *P. monodon*. Moreover, in some parts of the study area, mainly in My Xuyen, policy makers are currently grappling with growing concerns about the intensification of shrimp production in the Delta by farmers either practising higher stocking rates or abandoning rice–shrimp systems and instead practising double shrimp-cropping systems. Credit policy will have an important role to play, socially and environmentally, in controlling intensification to manageable levels.

Overall, one of the main advantages of the tidal-recruitment rice–shrimp system is that very little cash outlay is required, making it a low-risk and accessible technology for the poorer farmers in the saline-affected agricultural areas in the Mekong Delta. However, the long-term land loss raises concern about the sustainability of the system. The opportunity costs of the land loss are highlighted in the context of technological development. This paper argues that the economic problem of land loss is strongly connected to problems of accessibility to non–land degrading technology that is economic for poorer farmers who are dependent on the tidal recruitment of natural shrimp. The survival rates of *P. monodon* and associated risk are areas of particular concern in providing a viable alternative for farmers. Research evaluating the risks in the *P. monodon* system and farm management risk-spreading options (see Brennan this Report) for natural rice–shrimp farmers wanting to adopt the *P. monodon* technology could provide an important contribution in finding a solution to the land-loss problem addressed in this paper. Other technology options apart from the *P. monodon*-based systems are also important to consider as an alternative to the high water-exchange natural system, which may provide the same low water-exchange (non–land degrading) benefit as *P. monodon* technology but at lower income risk for farmers.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

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Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

CHAPTER 12

Land evaluation and land use planning of the area for rice–shrimp systems, Gia Rai District of Bac Lieu Province

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Abstract

The study area is situated in the southern part of National Highway No. 1 in Gia Rai District (Bac Lieu Province) where farmers have traditionally practised rain-fed rice cultivation. However, in the last five years the high profits possible from shrimp production have led many farmers in the study area to convert their rice fields to shrimp production. This has occurred with limited land use planning from government. In this study the suitability of land under different farming practices (in particular rice–shrimp farming) is assessed and recommendations are made for land use planning. These recommendations incorporated government objectives and the needs of local farmers. The study involved both soil and household surveys where a total of 249 soil observation points were made and a total of 264 households were interviewed about socioeconomic concerns. Land mapping units (LMU) were employed as a basis for the land evaluation. The land mapping units were identified on the basis of combinations of climatic, soil and hydrological characteristics — each of the 22 LMUs identified can be described in terms of soil type, rainfall, length of rainy period, maximum inundation depth, length of inundation period, tidal magnitude and present land use. The biophysical qualities of each LMU were combined with information about the required land qualities of four key land use types (LUT) to provide insights for land use planning in the study region. The land use types included in the study were double rice cropping (LUT1), rice–shrimp (LUT2), improved–extensive shrimp (LUT3), and extensive shrimp (LUT4). The results showed that only LUT3 and LUT4 were highly and moderately suitable for all LMUs, indicating that there is potential for fishery development in the study area. In several of the LMUs, however, LUT1 was found to be highly suitable and LUT3 and LUT4 only moderately to marginally suitable. The results from the assessment of land suitability were used to evaluate three land-use planning scenarios. These scenarios were: 1. maximise rice area; 2. maximise shrimp area; 3. develop separate zones for intensive rice cultivation and shrimp-based systems prioritising rice–shrimp systems. The local government objectives are most supportive of scenario 3; therefore, in this paper only the results for this scenario are shown[3].

ONE ISSUE THAT has been raised in studies on the agricultural development in the Mekong Delta over the last decade is protection of rice land in the coastal area of the Mekong Delta (Xuan and Matsui 1998). The rice area in the coastal zone is under severe pressure from rapidly increasing

[3] The results for scenarios 1 and 2 are found in the paper presented at the final ACIAR workshop, December 2000, Can Tho University, Vietnam.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

human population and conversion of rice fields into aquaculture farms. The high profits from shrimp production and the natural saline conditions have been a strong stimulus to the conversion to shrimp production.

Several sustainability issues have been associated with the fast-changing development in aquaculture production, including water pollution, shrimp disease and soil salinisation. Salinisation impacts arising from shrimp cultivation have meant that agricultural production in the coastal area has become very complicated and unstable. The very limited application of land use planning in the development of aquaculture systems in the coastal agricultural zone of the Mekong Delta has, in part, contributed to the sustainability problems that have been arising. The purpose of the research presented in this paper is to assist local government in Gia Rai to develop land use plans for the integration of shrimp-based systems, particularly rice–shrimp systems, in the study area.

The study was undertaken in the area situated south of National Highway No. 1 of Gia Rai District. Land evaluation techniques were drawn upon to assess the capacity and suitability of land in the study area for selected land use practices. The basis of the land evaluation was identification of land mapping units, each defined on the basis of combinations of climatic, soil and hydrological characteristics. The suitability of different land use types, particularly rice–shrimp systems, was assessed for each of the land map units. The study was conducted between October 1999 and July 2000 and involved a study team of scientists from the Soil Science and Land Management Department and the Farming System Research and Development Institute at Can Tho University. This paper is a summary of a larger research report presented at the final workshop of the ACIAR rice–shrimp project at Can Tho University in December 2000.

In addition to this study, a broader land evaluation study was also conducted as part of the ACIAR rice–shrimp project (Vo Quang Minh and Le Quang Tri 2000). In this broader study the land suitability was assessed for seven promising land use types across the ACIAR study region of My Xuyen and Gia Rai districts. The land use types considered in the study were: traditional rice and upland cropping (1); summer–autumn modern rice followed by copping of traditional rice (2); upland cropping (3); autumn–winter modern rice–shrimp/crab (4); shrimp only (5); salt pan and artemia (6); and forest and shrimp (7). The results from the land suitability evaluation indicated that land use types 3, 4 and 5 were the most suitable land uses in the ACIAR study area and that land use type 4 (rice–shrimp farming) was highly suited to more than 50% of the total area of the study region.

Land Use Planning

General overview

Land use planning is the systematic assessment of land and water potential, alternatives for land use, and economic and social conditions in order to select and adopt the best land use options (FAO 1993). Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future. The driving force in planning is the need for change, the need for improved management or the need for a quite different pattern of land use dictated by changing circumstances. Two conditions must be met if planning is to be useful: the need for change in land use or action to prevent some unwanted change must be

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

accepted by the people involved, and there must be the political will and ability to put the plan into effect.

Land use planning for rice–shrimp system

Planning to make the best use of land is not a new idea in the Mekong Delta, particularly in Gia Rai. Over the years, farmers have made plans season after season, making decisions on what to grow and where to grow it. Their decisions have been made according to their own needs, their knowledge of the land and technology, and labour and capital available. As size of the area, the number of people involved and the complexity of the problem increase, so does the need for information and rigorous methods of analysis and planning. Land use planning recommendations are presented in this study. These recommendations are based on results from the land evaluation and incorporate objectives of local government, including the identification of the areas most suited to rice–shrimp farming.

Land use planning objectives

The land use planning objectives for local government in Gia Rai identified in this study are outlined below:

- keeping rice production for food security
- overcoming production restrictions arising from saline intrusion and implementing land use planning to take advantage of saline conditions, such as production of shrimp for the export market
- identifying land areas with potential for aquaculture production, particularly shrimp cultivation
- increasing areas of rice–shrimp and shrimp systems
- establishing two production areas, one for rice and rice–shrimp, and another for shrimp production only
- increasing farmer income.

Physical conditions in the study area

General information on the study area

The research area in this study was made up of around 50 000 ha in Gia Rai District (Bac Lieu Province) located south of the National Highway No. 1 and consisted of seven villages and three towns. The area is affected by saline water intrusion in the dry season. In the rainy season, flooding affects the area.

The total population in Gia Rai District was estimated at 240 339 people in 1999. The majority of the population is made up of Kinh people, although in 1999 around 9411 Khmer people were living in the district. The average population density of the district is about 294 people/km^2, with about 5.1 people per household. The distribution of people in the district is not the same for each village — most of people are concentrated along the canal and along the road, and the population becomes more scattered in the inland areas.

Climatic conditions

Climatic conditions of Bac Lieu Province (rainfall distribution, length of rain-fed season, temperature, air humidity and evaporation) are generally the same as Mekong Delta conditions, with dry and wet seasons during the years.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Temperature (^oC)
Average air temperature of different months change from 25^oC to 28.4^oC, highest in April and lowest in January.

Rainfall distribution
Total average rainfall in the year is about 1800 mm, concentrated mostly in the rainy season. About 90% falls from May to November, with highest levels recorded in September (249 mm) and October (295 mm). Based on data collected and crop water requirements, the total rainfall during this rainy season is just enough for two rice crops in the case of rain-fed cultivation.

Evaporation
The average monthly evaporation in several years of the research area changes from 48 mm in July to 111 mm in March. In the research area, the highest evaporation occurs in the dry season from December to March.

Hydrological conditions

Gia Rai District, located along the coast, is subject to salt-water intrusion from the sea during the dry season. Therefore, all canal and river systems are affected by the semi-tidal regime of the East Sea through Ganh Hao River and Ho Phong-Ganh Hao Dinh. The salinity-control sluice gate system on the northern side of Highway No. 1 distributes to most canals south of the highway. Tidal fluctuation is very high, especially near the sluice gates, eg. in Ganh Hao the average tidal fluctuation is 2.85 m. Saline water intrusion is the major problem for agriculture in the district, especially in the southern part of National Road No.1 of district which is affected by tidal movement.

Soil

Soils in Gia Rai District generally, and in the study area particularly, change greatly with landform differences from inland to the coast; they also have different soil development processes. The soils located in the high topography (inland) were developed with the presence of B horizon in the profile. In contrast, near the coast the soils are still young and less developed because of the daily tidal-flooding effect.

Based on the soil map of Gia Rai District, 1/25.000 compiled by the National Institute for Agricultural Planning and Projection (NIAPP), 20 transects were made for the soil survey to correct the existing map. The survey results obtained for the study area can be shown through the soil map at the scale of 1:25 000 (NIAPP 1995). Generally, all soils within the study area derived from a unique parent material of recent alluvial deposits, with an age less than 10 000 years (late Holocene). Soil processes are mainly alluvial accumulation from marine origin. In this study, three major soil groups with eleven soil types were found. These are outlined in Table 1.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 1. Soil types in the study region.

Soil type description	Code
Group 1: slightly saline soils	
1. Slightly saline soils	Mi
2. Slightly saline developed soils	Mie
3. Slightly saline deposited alluvial soils	Mif
4. Slightly saline developed acid sulphate soils	Srj2Mi
5. Slightly saline developing acid sulphate soils	Srj1Mi
Group 2: saline acid sulphate soils	
6. Saline acid sulphate soils	Sj2P2M, Sj2M
7. Saline strongly acid sulphate soils	Sj1P1M
8. Saline shallow potential acid sulphate soils	Sp1M
9. Saline deep potential acid sulphate soils	Sp2M
Group 3: permanent saline soils	
10. Permanent saline soils	Mn
11. Permanent saline potential acid sulphate soils	Sp1Mn

Present land use in the study area

Gia Rai District is dominated by mixed-farming systems along the coast. Crops such as rice play a significant role for farmers in fulfilling subsistence requirements, while others crops, such as upland crops, satisfy the income or cash requirements of farm households. Rice is grown mostly on alluvial soils. There are two types of rice grown in the area: high-yielding varieties with a short growing period, and high fertiliser and pesticide requirements; and traditional rice, with a long growing period. The traditional varieties tend to have medium to low yields but are appreciated for their taste. Most farm households keep livestock, such as cows, water buffalo, chickens and pigs, for different purposes. Cows and water buffalo are used for ploughing and transportation, pigs are kept for their meat and chickens for their meat and eggs, which are often sold by households at the local markets.

Since the early 1990s, the area of fishery cultivation, especially shrimp cultivation, has been increasing each year. In 1999 the total area of aquaculture (shrimp and other fish) in Gia Rai (GR) was 23 865 hectares (30% of the area of the district) and the total production of shrimp was about 2456 tonnes (this includes shrimp production in rice–shrimp and shrimp monoculture systems).

Methods and data in the land evaluation

This study was conducted between November 1999 and July 2000 in the following stages:

- Stage 1: November 1999–February 2000: prepare field map, training and documentation
- Stage 2: February 2000–March 2000: soil survey and farmer interviews, other data collection
- Stage 3: March 2000–July 2000: post-fieldwork, soil analysis and map making, report writing and presentation.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Surveys and data

Monthly climatic data from the last ten years (1989–1999) were collected at the nearest meteorology station (Bac Lieu Station). Data and maps of hydrology were also collected. These data were used to evaluate the effect of climate and hydrology on crop cultivation and cropping systems in the area. In the research area, besides soil survey and field data collection, data on maximum inundation depth, length of flooding, and the saline water situation were collected for hydrological evaluation.

The precise area and administration map for the study area was obtained from the Cadastral data of Gia Rai District (at scale 1:25 000). In total, 249 survey locations were identified through the 20 transect walks that crossed over the study area.

The soil survey activity was conducted from February to March 2000. Three survey groups were formed and the survey performed on the basis of the predefined observation points and field truth measurements.

Socio-economic survey

Present land use systems, cultural practices and related socioeconomic dimensions were investigated through farmer interviews. A total 264 households were interviewed in the socioeconomic survey by questionnaire. The main contents of questionnaire were:

- household-farm resources
- farm activities and farm inputs
- on-farm, non-farm and off-farm income
- farm household expenditures
- other economic factors important to land use: credit, marketing, agricultural services
- farmers' problems: physical, biological and socio-economic
- farmer suggestions.

Land evaluation procedure

The land evaluation procedure involved matching land quality characteristics in defined land mapping units (LMU) with the land quality requirements of specified land use types. Through such a matching, the land suitability can be evaluated for different land use types for each of the LMUs evaluated in the study (FAO 1976).

Details of the land evaluation procedure and land use planning are shown in Figure 1. The purpose of the land evaluation is to assess the suitability of different land use types given the land qualities in the study area. The land evaluation results can then be used in combination with development objectives to conduct land use planning. Each step in the land evaluation in this study is described below.

Step 1. Define the land mapping units.

The LMUs are based on combinations of climatic, soil and hydrological characteristics. Twenty LMUs were identified in this study. The characteristics of each LMU are described in terms of soil type, rainfall, length of rainy period, maximum inundation depth, length of inundation period, tidal magnitude and present land use. Classes for each of the physical characteristics are shown in Table 2.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 2. LMU quality characteristics.

Characteristic	Class
Soil type	These were shown in Table 1.
Rainfall amount (mm)	1. <1500 2. 1500–1600 3. 1600–1700 4. 1700–1800 5. 1800–1900
Rainfall period	1. 6 months 2. 6–7 months
Inundation length (cm)	1. <40 2. 40–60 3. >60
Inundation depth (max)	1. 5 months 2. 6 months 3. Daily tide
Tidal magnitude (cm)	1. <250 2. 250–300 3. 300–350 4. >350
Land use	1. Rice–shrimp (RS) 2. Shrimp (S) 3. Rice (R)

The land characteristics for each of the LMUs are shown in Table 3. A map of land units is shown in Figure 2.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 3. Land quality characteristics for LMUs in the study area.

LMU	Climate		Soil type	Hydrology			Present land use
	Rainfall (mm)	Rainy period (month)		Magnitude (cm)	Depth of inundation (cm)	Length of inundation (month)	
1	<1500	6	Sj2M/Sp2M	250–300	>60	5	S
2	150–1600	6	Sp2M	250–300	40–60	5	S
3	<1500	6	Mif/Srj2Mi	<250	<40	6	R
4	1500–1600	6	Mi	250–300	40–60	5	RS
5	1600–1700	6	Mie/Srj2Mi	250–300	40–60	5	RS
6	1700–1800	6–7	Mie/Srj2Mi	<250	<40	5	RS
7	1700–1800	6–7	Sj1P1M	300–350	>60	Tide	S
8	1700–1800	6–7	Sj1P1M	300–350	40–60	Tide	S
9	1700–1800	6–7	Mie	<250	40–60	Tide	S
10	1800–1900	6–7	Mif	<250	40–60	Tide	RS
11	1800–1900	6–7	Mif/Srj2Mi	<250	40–60	Tide	R
12	1700–1800	6–7	Sj2P2M/ Sj2M	300–350	40–60	Tide	R
13	1600–1700	6	Sj2P2M	300–350	>60	Tide	S
14	1600–1700	6	SP2M	<250	40–60	5	S
15	1500–1600	6	SP1M	250–300	40–60	6	S
16	1600–1700	6–7	Srj1Mi	300–350	>60	6	S
17	1600–1700	6	Sj2P2M	300–350	<40	Tide	RS
18	1600–1700	6	SP1Mn	>350	>60	Tide	S
19	1500–1600	6	Srj2Mi	250–300	<40	6	R
20	1500–1600	6	Srj2Mi	250–300	<40	6	RS

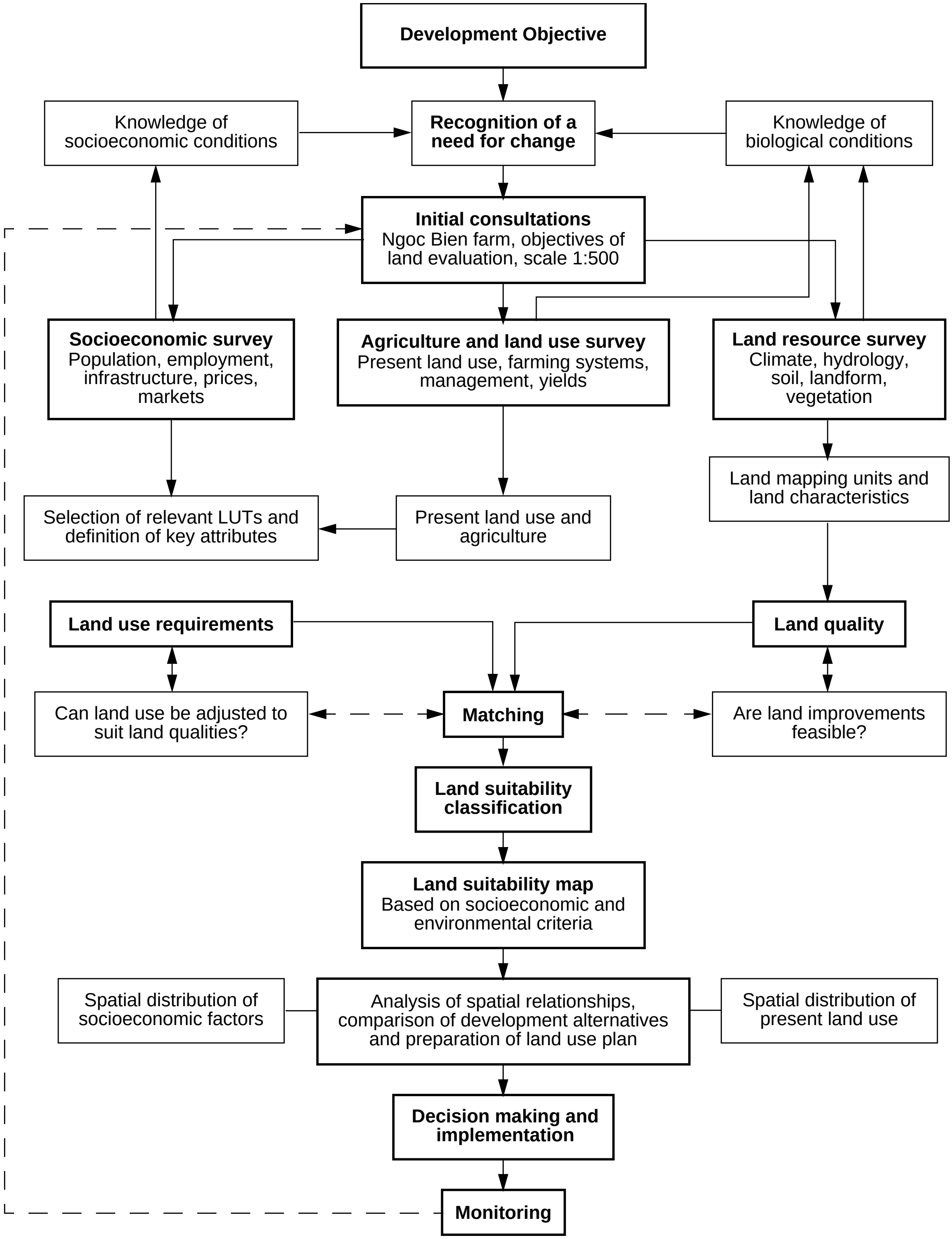

Figure 1. Procedure of land evaluation and land use planning for Gia Rai District.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

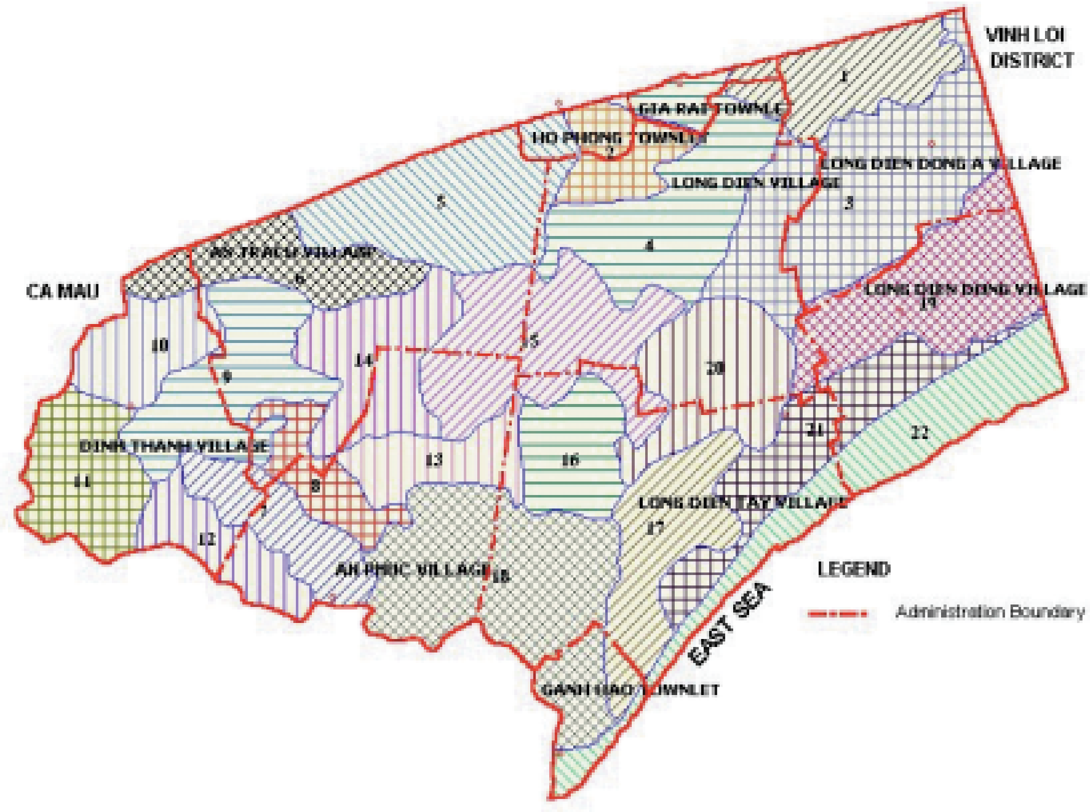

Figure 2. Soil units in the study area.

Step 2. Select promising land use types.

Selection of feasible land use types (LUT) involved initial selection through consultations with local officers and farmers. This initial list was then reduced using a 'filtering' system based on the government development objectives that have been listed above.

Four promising LUTs were chosen for consideration in an evaluation of land suitability in Gia Rai District. They are:

- LUT1: double cropping of rice
- LUT2: rice–shrimp
- LUT3: improved extensive shrimp
- LUT4: extensive shrimp

Step 3. Identify the land use requirements for the LUTs with the land qualities of the LMUs.

This step in the land evaluation involves identifying land use requirements for each LUT (FAO 1976). It is necessary to establish the following for each LUT:

- the conditions that are best for its operation
- the range of conditions that are not optimal but still acceptable
- the conditions that are unsatisfactory.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

The land quality requirements for each of the four land use types considered in this study were assessed against the following land quality criteria: availability of soil, availability of fresh water, capacity of irrigation and drainage, and flooding hazard. The four land quality requirements were rated according to their suitability for each of the four LUTs. The suitability ratings are as follows:

- S1: high suitability
- S2: moderate suitability
- S3: marginal suitability
- N: not suitable

The suitability ratings for the rice–shrimp system are shown in Table 4. The factor ratings for the other LUTs can be found in the full workshop paper.

Table 4. Factor rating of LUT2: rice–shrimp system.

Land quality requirement	Diagnostic factors	Factor rating as suitability			
		S1	S2	S3	N
Availability of soil	Soil types	Mif Mie Srj2Mi Sj2M Sj2P2M	Srj2Mi Sj2M Sj2P2M Sj2P2M	—	Sp1 Mn Sp1Mn Sp1M
Availability of fresh water	Length of rainy period (month)	6	5–6	<5	—
Capacity of irrigation and drainage	Magnitude (cm)	>250	<250	—	—
Flooding hazard	Max. inundation depth (cm)	<40	40—60	60–100	>100

Step 4. Land suitability classification.

In this step, the suitability of the different land qualities was combined to assess the overall suitability of each LMU for each LUT. In assessing the suitability of LMUs for crop combinations, the first step is to obtain suitability assessments for each the crops concerned. In general, the suitability for a cropping system based on two or more crops will be not higher than the lowest of the crop assessments (Le Quang Tri et al. 1993).

Land evaluation results

The results of the land suitability classification are shown in Table 5. Based on the suitability classification, promising land use types were identified for each of the LMUs.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 5. Land suitability classification, priorities and alternatives in the study area.

LMU	LUT1	LUT2	LUT3	LUT4	Land use type	
	Land suitability classification				Priorities	Alternatives
1	N	S1	S1/S2	S1/S2	2	3, 4
2	N	S1	S1/S2	S1/S2	2	3, 4
3	S1	S2	S1/S2	S1/S2	1	2, 3
4	S1	S2	S1/S2	S1/S2	1	2, 3
5	S2	S2	S1/S2	S1/S2	2	3, 4
6	S2	S2	S2	S2	2	3, 4
7	N	S2	S2	S2	2	3, 4
8	N	S2	S2	S2	2	3, 4
9	S2	S2	S2	S2	2	1, 3
10	S2	S2	S2	S2	2	1, 3
11	S2	S2	S2	S2	2	1, 3
12	S2	S2	S2	S2	2	3, 1
13	S3	S2	S1/S2	S1/S2	3, 4	2
14	N	S2	S1/S2	S1/S2	3, 4	2
15	N	S2	S1/S2	S1/S2	3, 4	2
16	S2	S2	S1/S2	S1/S2	3, 4	2, 1
17	S2	S2	S1/S2	S1/S2	2	1, 3
18	N	S2	S1/S2	S1/S2	3, 4	2
19	S1	S2	S1/S2	S1/S2	1	2, 3
20	S2	S2	S1/S2	S1/S2	2	1, 3

As shown in Table 5, only improved–extensive shrimp (LUT 3) and extensive shrimp (LUT 4) were either highly or moderately suitable land uses for all LMUs, which indicates potential for fishery development in the study area. The rice–shrimp system (LUT2) is highly suitable in low-topography land with proper tidal regimes and either saline or slightly saline acid sulphate soils, as found in LMUs 1, 2, 5, 6, 7, 8, 9, 11, 16, 17 and 20. These LMUs are also suitable for improved–extensive shrimp cultivation. The land use types for extensive and improved–extensive shrimp cultivation were highly suitable in LMUs 13, 14, 15, 16 and 18, which experience deep flooding, have saline and extremely acid sulphate soils, and are not suitable for rice. The priority areas for rice cultivation are mainly located in LMUs 3, 4, 19, which have high topography, slightly acid soils or alluvial soils, and are surrounding by strong dikes for protection against salt-water intrusion into the field. Double cropping of rice (LUT1) was found to be unsuitable in low land with acid sulphate soils, such as LMU 1, 2, 7, 8, 14, 15, 18, 21 and 22.

Land use zoning

Based on the results shown in Tables 4 and 5, some suggestions are provided in this section for the development of land use zones in the study area as an approach to land use planning and development. Six land use zones are identified for the study area. A map of the suggested zones is shown in Figure 3 and details of the zone areas are outlined in Table 6.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

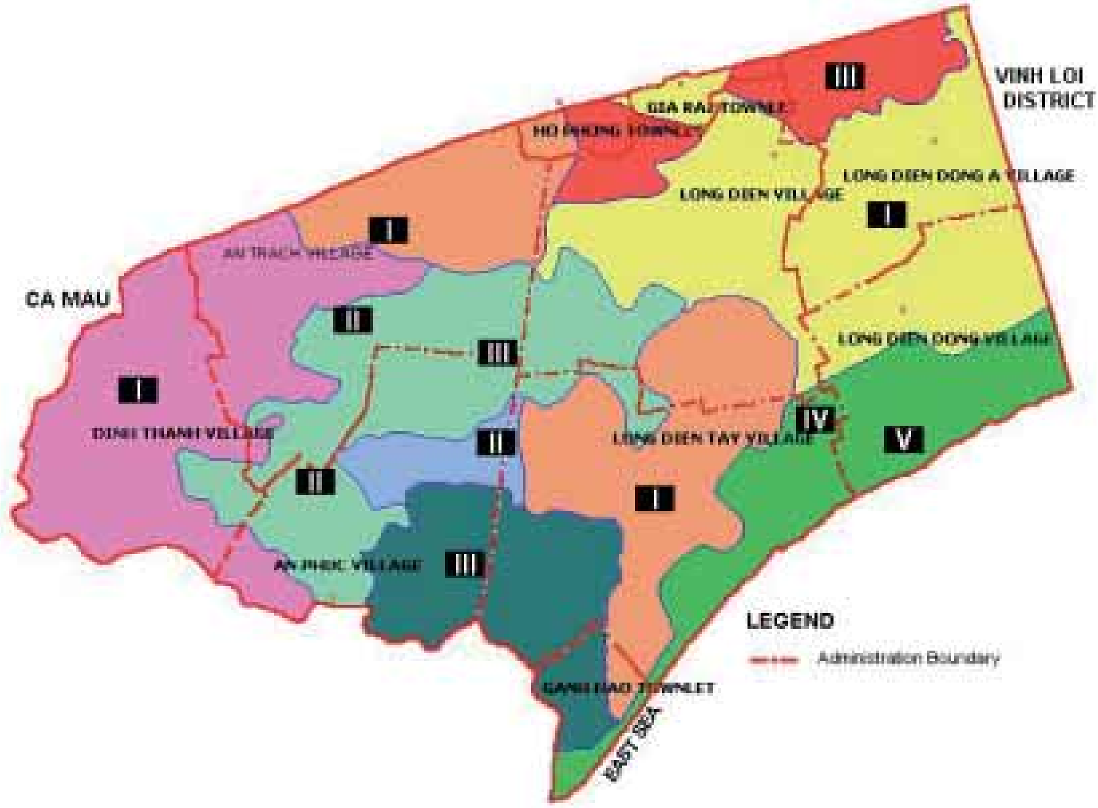

Figure 3. Suggested land use zones in the study area.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Table 6. Land use suggestion and situation in the Southern part of National No.1 of Gia Rai District.

Zone	Land use types		LMU	Comments	
	Priorities	Alternatives		Opportunities	Limitations
I	Rice cropping	• Rice–shrimp • Improve extensive shrimp	3, 4, 19	• Dike system • High topography, good drainage, slightly/non-acid sulphate soils • Intensive rice cultivation with high and stable yield	• Drought in some years • Less profit as compared with shrimp • Low magnitude of tide so the water cannot reach the field regularly
II	Rice–shrimp	• Rice cropping • Improved–extensive shrimp • Extensive shrimp	9, 10, 11, 17, 20	• Source of salt water during the dry season • Low to medium topography, high magnitude • Slightly/non acid sulphate soils	• Canal system for drainage and irrigation incomplete • Poor technical practices
III	Rice–shrimp	• Improved–extensive shrimp • Extensive shrimp	1, 2, 5, 6, 7, 8, 12	• Source of salt water during the dry season • Low to medium topography, high magnitude	• Acid sulphate soils • Canal system for drainage and irrigation incomplete • Poor technical practices of rice–shrimp system and shrimp cultivation • Pollution of water quality

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Zone	Land use types		LMU	Comments	
	Priorities	Alternatives		Opportunities	Limitations
IV	Shrimp	• Rice–shrimp	13, 14, 15, 16, 18	• Source of salt water during the dry season • Low to medium topography, high magnitude • High capacity of drainage and irrigation	• Extremely acid sulphate soils • Not yet completed the canal system for drainage and irrigation • Poor technical practices of rice–shrimp system and shrimp cultivation • Pollution of water quality
V	Salt pan				
VI	Mangrove forest + fishery				

Land use planning scenarios

The suggested land zoning shown in Table 6 and Figure 3 was based on the results of the evaluation of land suitability of LMUs for different land use types. In this section, land zoning recommendations are made based on the land use planning objective (scenario 3 in Abstract) to develop separate zones for intensive rice cultivation and shrimp-based systems prioritising rice–shrimp systems. This objective was identified through consultations with local government in the study area. Details of this scenario are outlined in Table 7, and the recommended land use zones under this objective are outlined in Table 8.

Table 7. Defining a specific land use planning objective.

Objective	• Protect the area with intensive rice cultivation (high yield) and separate the area for shrimp-based systems, prioritising rice–shrimp systems.
Conditions	• Prioritise rice development in high topography land. • Develop rice–shrimp systems in current rice areas that have medium to low topography. • Develop mono-shrimp systems in low land not suitable for rice. • Select high-yielding rice varieties and traditional rice varieties (with high quality taste).
Recommendations	• Base farm management practices for rice–shrimp systems and shrimp cultivation on experience, experiments and trials. • Select high-quality shrimp seed. • Establish a network of shrimp seed supply in the region. • Construct a canal system for irrigation and drainage. • Select high-quality varieties of rice for export markets.

Table 8. Zone recommendations of selected land use types in the study area.

Zone	Selected land use type	Area of present land use		Area after planning		New land allocation	
		Ha	%	Ha	%	Ha	%
I	Rice	12,660	34.3	6,430	17.4	–6.23	–16.8
II	Rice–shrimp/Rice/ Shrimp	300	0.8	12,630	34.2	12.43	33.6
III	Rice + shrimp/Shrimp	24,000	65.0	4,322	11.7	–6.20	–16.8
IV	Shrimp + rice			6,901	18.7		
V	Shrimp			6,577	17.9		
	Total	36,960	100	36,960	100		

A map of the recommended land use for the study area based on the defined objective is shown in Figure 4. More detail on the area of planning and transformation of selected land use types for each of the villages in the study area is outlined in Table 9.

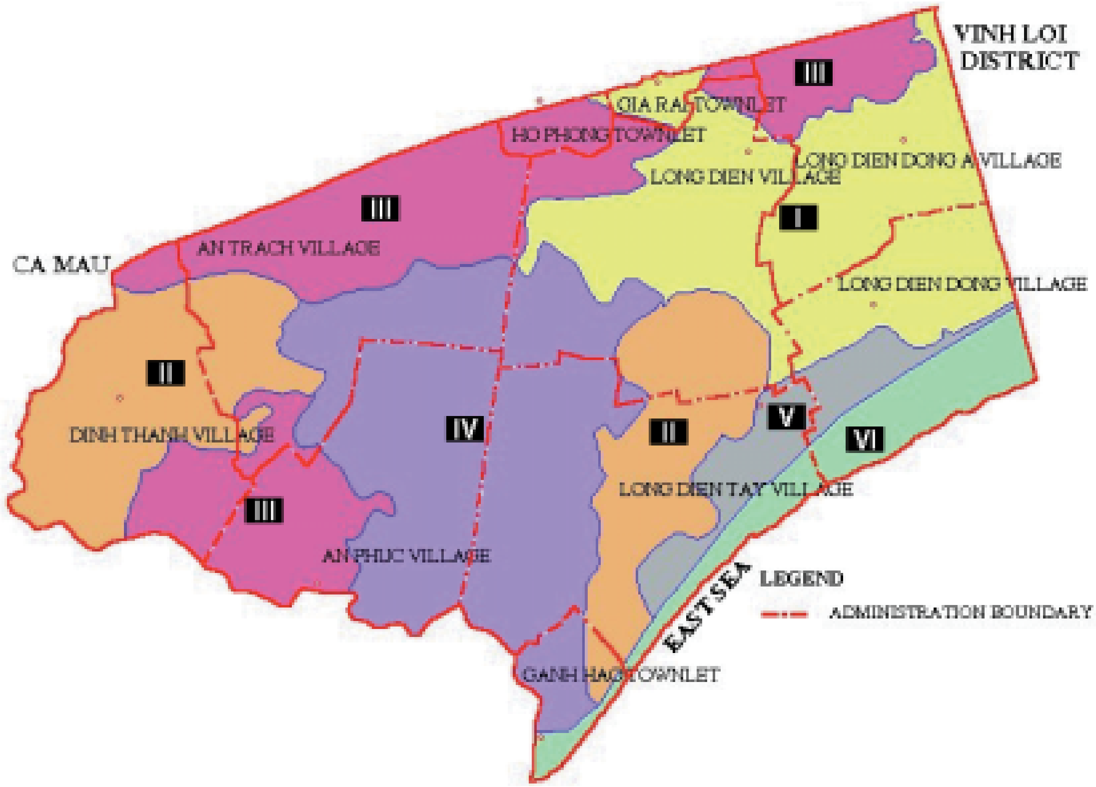

Figure 4. Recommended land use map based on defined planning objective.

Table 9. The area of planning and transformation of selected land use types in the study area, based on the defined planning objective.

Village	Selected land use type	Area of land use in 2000		Area of planning		Area of transformation	
		Ha	%	Ha	%	Ha	%
Long Dien Dong	Rice	2 750	100	2 750	100.6	—	—
	Rice + shrimp	—	—	—	—	—	—
	Shrimp			—	—	—	—
Long Dien Dong A	Rice	1 931	56.6	1 878	55.0	–53	–0.1
	Rice + shrimp	1 483	43.4	1 536	45.0	53	0.1
	Shrimp			—	—	—	—

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Village	Selected land use type	Area of land use in 2000		Area of planning		Area of transformation	
		Ha	%	Ha	%	Ha	%
Long Dien	Rice	4 064	53.7	1 293	17.1	–2 771	–7.5
	Rice + shrimp	3 500	46.3	3 677	48.6	2 771	7.5
	Rice–shrimp/ Shrimp			1 601	21.2		
	Shrimp			993	13.1		
Long Dien Tay	Rice	1 041	18.8	509	9.2	–532	–1.4
	Rice + shrimp	4 500	81.2	855	15.4	532	1.4
	Rice–shrimp/ shrimp			2 404	43.4		
	Shrimp			1 773	32.0		
Dinh Thanh	Rice	1 980	47.0	0	0.0	–1 980	–47.0
	Rice + shrimp	2 232	53.0	1 833	81.1	396	47.0
	Rice–shrimp/ shrimp			795	18.9		
An Trach	Rice	173	2.3	0	0	–173	–2.3
	Rice + shrimp	7 239	97.7	4 614	62.3	173	2.3
	Rice–shrimp/ shrimp			1 893	25.5		
	Shrimp			905	12.2		
An Phuc	Rice	—	0.0	0	0	—	—
	Rice + shrimp	4 006	100	1 508	37.6	—	—
	Shrimp			2 498	62.4		
Gia Rai town	Rice	418	61.5	0	0	–418	–61.5
	Rice–shrimp/ shrimp	262	38.5	680	100	418	61.5
	Shrimp			—	—	—	—

Village	Selected land use type	Area of land use in 2000		Area of planning		Area of transformation	
		Ha	%	Ha	%	Ha	%
Ho Phong town	Rice	259	38.9	0	0	–259	–38.9
	Rice–shrimp/ shrimp	406	61.1	161	24.2	259	38.9
	Shrimp			504	75.8		
Ganh Hao town	Rice	39	5.5	0	0	–39	–5.5
	Rice–shrimp/ shrimp	672	94.5	302	42.5		
	Shrimp			409	57.5		
Total		36 955	—	36 955	—	—	—
Salt pan		1 174	—	1 174	—	1 174	—
Forest + fishery		2 223	—	2 223	—	2 223	—

Final recommendations

The following recommendations are primarily focused on broader planning issues that will be important to address in supporting the implementation of the land zoning recommendations made in this study.

- Rice–shrimp and shrimp are most suitable in the lowland areas of the study region, which are affected by daily tidal flooding in the later part of the year.
- Four land zoning recommendations have been identified, based on the land evaluation results. Five zones are proposed for the different land use types, shrimp being recommended as the primary product for farmers.
- The best management model of the rice–shrimp and shrimp-based systems should be extended to the farmers, through farm demonstrations and field days, to support sustainable development of these systems.
- Greater attention must be given to the availability of credit to support farmers’ adoption of the shrimp-based systems in the area.
- Infrastructure design (especially canal systems) in the villages of the southern part of Gia Rai District should be based on the proposed land use planning zones.
- Water quality should be monitored and improved in areas where shrimp-based systems are expanded.
- A network for the supply of shrimp seed should be established to overcome the significant difficulties experienced in the Delta as a result of inadequate supplies of good-quality shrimp postlarvae.

- High-quality varieties of rice should be selected for export.
- Market improvement for rice should be addressed in order to stimulate farmers' investment in land improvements for food security objectives.

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APPENDIX

Recommended best management practices for the shrimp component of the rice–shrimp farming system

IN BROAD TERMS the adoption of the rice–shrimp system of shrimp production can be viewed as a best management practice for achieving a balance between economic development, minimizing risks and conserving the environment. The areas used for rice–shrimp farming have traditionally been used for wet season agricultural crops and do not impinge on mangroves. The shrimp farmed in this system are stocked at low densities and feed inputs to the ponds are low. The freshwater rice crop provides a buffer between the brackish water shrimp crops. The inundation of saline water during the dry season does not appear to lead to a long-term build up of salts in the soil, thus rice yield performance is not compromised in the rice–shrimp system. Benefits for economic sustainability include diversification of production and improved incomes. Social sustainability benefits include jobs, decreasing poverty and improvement to food security. These characteristics of the rice–shrimp system avoid many of the negative impacts that can results from intensive shrimp monoculture. Thus, in common with other extensive systems, the rice–shrimp system appears to one of the more economically and ecologically sustainable approaches to shrimp farming.

The following recommendations about the best management practices are based on the outputs from the research described in this technical report. These recommended best management practices (BMPs) are intended for use in conjunction with the extension, pamphlets, video and CD-ROM produced by the Mariculture Department of Canto University with assistance from DANIDA. The extension material has been widely distributed to farmers and extension officers in the region and additional copies are available from the Mariculture Department. These BMPs are specific to the rice–shrimp system and are not necessarily appropriate for other forms of shrimp farming (eg shrimp monoculture) in the region.

Rice–shrimp pond design and construction

The typical layout of a rice–shrimp farm is shown schematically in Figure 1.

The recommended dimensions for a rice shrimp farm are as follows:

Ratio of Trench to platform

- 20–40% trench.
- 80–60% platform.

Water level from platform floor	50 cm
Trench Depth (bottom of trench to platform)	50–70 cm

Trench Width

- at bottom 2–2.5 m.
- at top, 3–4 m.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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ACIAR Technical Reports No. 52e
(printed version published in 2003)

Care needs to be given to maintaining the strength of the dikes that border the canals or river that supplies the water for the pond. Dike strength is especially important when the dike borders the river. The different ways of ensuring dike strength include:

- Mechanical compaction using a tractor or other heavy machinery is recommended where possible.
- Plastic sheeting can be used in addition to mechanical compaction to prevent leakage.
- A column of clay can be inserted along the centre of the dike. A column along the centre of the bordering dikes can be dug out and filled with fine clay particles (mud) from the bottom of the canal or polder to prevent water leakage. Strength can be improved by compacting using a tractor with a "packer-head".

The recommended dike dimensions are:

Dike Width

- Bordering dikes: 5 m.
- Periphery dikes: at least 3 m width at bottom and around 1.5 m at top.

The required width will depend on the soil type. Heavy clay soils will generally be less pervious and therefore dike width may be reduced.

Dike Height

- 80 cm above the platform.

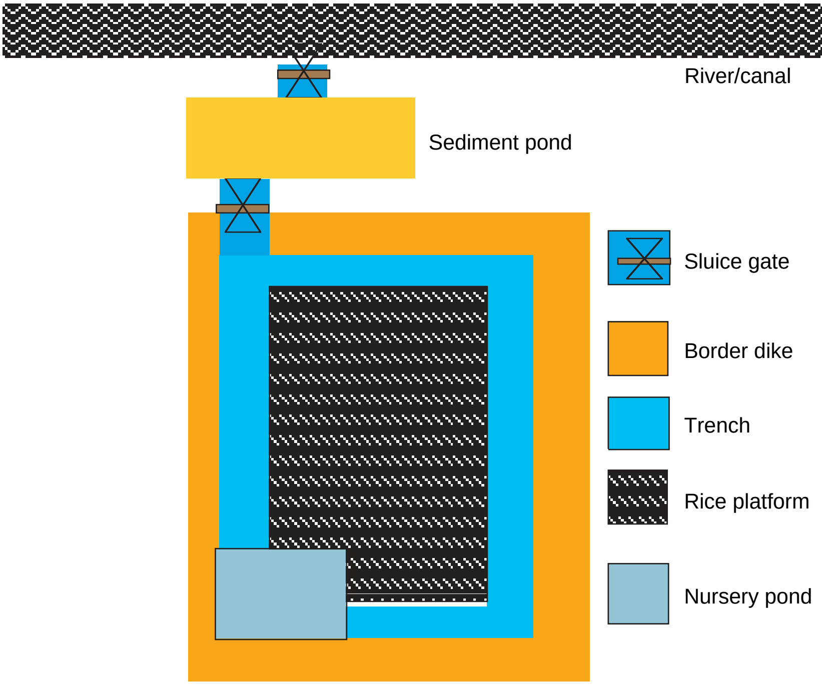

Figure 1. Schematic of the typical layout of a rice–shrimp farm.

Collaboration may be needed with neighboring rice–shrimp farmers. For example, in the case of adjacent shrimp ponds, a 2 m width (4 m in total) for adjoining periphery dikes would be sufficient.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

During the construction of the dike we recommend that lime be added to the clay to counteract the effects of any acid-sulfate residue. We recommend that lime is added in the form of standard agricultural lime ($CaCO_3$). Agricultural lime is preferable to quick lime (CaO) which is more expensive and the dust is toxic. For additional information see the pond liming section.

Sediment pond

The primary purpose of the sediment pond is to improve water quality by allowing sediment to settle prior to filling the pond. The sediment pond should not be deeper than the canal.

- 10% of total pond area (not including the dike) (eg. 1000 m^2 for a 1 ha pond).
- Depth: 1.5 m minimum depth, measured from top of dike.

Nursery pond

The purpose of the nursing pond is to provide a small area within the pond, separated from the rest of the pond by a clay wall or net, in which the newly stocked postlarvae can be monitored for about three weeks before they are released into the main pond.

Size

- For a 1 ha pond the nursery pond should be 500 m^2 (5% of 1 ha). This size is based on a stocking density of 100 postlarve/m^2 in the nursery pond. This will supply enough postlarvae to stock the 1 ha pond at the recommended 5 postlarve/m^2.

  The nursery pond should be at the opposite end of the polder to the sediment pond.

Rice stubble

Rice stubble may assist in the natural development of good pond conditions (such as growth of epiphytes); however too much rice stubble is undesirable because of the high organic content. If rice stubble is kept the following method is suggested:

- After cutting rice stubble to around 20 cm, submerge the rice stubble in water for 4–5 days to soften stubble, then harrow the wet field and flush the pond twice to remove excess organic matter.
- If no tractor is available, removal of the majority of rice stubble is recommended.

Polder drying

- 5–7 days should be allowed for pond drying.
- Avoid deep cracking of soil to prevent salinisation of sub-soil, that can affect subsequent rice-crop.

Use of derris

- During the drying of the platform, application of liquid mix of Rotenone root (Derris powder) to the trench.
- Recommended application rate: drop water level at 20 cm in the trench and apply 7 to 8 kg of dry rotenone per 3000 m^2. Apply before liming.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Pond preparation liming

- Apply lime to both sides and bottom of trench.
- Application rate: this depends on soil acidity; the general range is 5–10 kg per 100 m^2.

Filling water

- Following high tide, allow a period of around half-an-hour for sedimentation of suspended solids.
- Check the pH of the canal water before filling. Do not fill if the pH is <7.5.
- Fill the sediment pond over 2–3 days from the top 20–30 cm of canal water.
- When filling the sediment pond the water should be filtered through a mosquito net (1 mm mesh) to prevent the incursion of fish.
- Water should be kept in the sediment pond for 5–7 days or until the Secchi depth is greater than 40 cm.
- Water flow from the sediment pond into the rice–shrimp pond should be filtered through fine mesh (100–200 micron mesh). Typically the mesh consists of a conical silk sock 4–5 m. This protocol should be used for regular exchanges each spring tide.

Fertilizing the nursery and grow-out pond

Fertilization is only needed if a phytoplankton bloom does not establish naturally. There will usually be adequate nutrients in the water from soil or canal, so in most cases additional fertilization should not be necessary. If there is no bloom a locally-available organic fertilizer such as duck or pig manure instead of manufactured fertilizer can be used. In this case, place the fertilizer in a mesh bag and put the bag(s) in the pond, to avoid fouling the bottom. If it is hard to establish a bloom this may be due to excessive blue–green algae removing nutrients. In these circumstances the algae needs to be removed manually. If organic fertilizer is not available the following inorganic fertilizer can be applied:

- NPK (20:20:15) combined with Urea (46%N) at ratio of 4:1. 3–5 kg of this ratio per 1000 m^2.

Stocking the ponds with shrimp postlarvae

Timing of stocking

Postlarvae should not be stocked into the nursery or grow-out ponds if the salinity is <5–6 ppt. The local extension centre should monitor the salinity level and inform farmers.

Source age and stocking density of postlarvae:

The ideal age is postlarvae at stage 15 to 20 (PL 15–20).

If possible obtain postlarvae that have been acclimated to nursery pond conditions.

The recommended stocking density is 5–7 postlarvae/m^2.

Postlarval stress tests (see video)

- Visual swim test, colour and activity.
- Formalin test: 150 ppt for 20–30 minutes. Sub-sample for test of 20PL × 3. If more than 3–4 in each replicate die following the stress test, then reject.

Formalin tests are widely used — but do not indicate the reason for the poor survival of the postlarvae (see video demonstration).

Management of postlarvae

Acclimatising postlarvae

When the postlarvae arrive from the hatcheries they need to be acclimatised from 25 ppt to 5 ppt. They also need to be acclimatised to the nursery pond temperature.

- A period of acclimation of 2 days is recommended.
- It is crucial that the change in salinity is not greater than 5 ppt for each reduction in salinity (4–5 hours between changes).
- Aeration of the acclimation tank is recommended.
- Feeding with feed pellets used in the nursery is recommended.

Nursery management

- Nursery stocking rate should be 100–150 postlarvae/m^2.
- Commence feeding with the same feeds used in the nursery that provided the postlarvae.
- The feeding should occur three times at night and twice during the day.
- Quantity of feed per PL 0.5 kg per 10,000 PL per day.
- Monitor feeding with feed trays of 0.25m^2.

Pond management

Reducing sedimentation

The ACIAR study revealed that the traditional practice of recruiting native shrimp (often referred to as natural shrimp) is not sustainable because of the loss of land from pond sedimentation due to the high water exchange required for natural recruitment. The more recently developed system of stocking with *P. monodon* hatchery-reared postlarvae, combined with low water exchange, is the recommended best practice. However, there are some areas where the natural conditions are well suited for native shrimp farming. In other areas farmers would like to switch from native shrimp farming to the hatchery based *P. monodon* system, but are unable to obtain postlarvae. Thus, in recommending the hatchery based, low-water exchange system we recognize the need for flexibility during the transition towards improved farming practices.

Low water exchange

The best management practice for ponds stocked with postlarvae from hatcheries is to use minimal water exchange. Using this pond management strategy water is only exchanged to control water quality (not for recruitment of natural shrimp). If the phytoplankton bloom is dense take a reading with a Secchi disc. If the Secchi depth is less than 25 cm exchange water

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

until a 25 cm reading is obtained. The pH of the canal water should be checked before exchanging water. It may take 2 or 3 water exchanges before a Secchi reading of 25 cm is reached. On each occasion no more than 20% of pond should be exchanged.

Monitoring water quality

- Monitoring pond water. Daily water quality checks are recommended. Use of a Secchi disc is recommended. If the Secchi depth is greater than 40 cm, add fertilizer (see above) for 2 to 3 days in a row to promote phytoplankton growth.
- Monitoring pH levels. The optimal range is 7.5–8.5. Monitoring is recommended every 3 days. Monitor in the morning (6–7 am) and the evening (3–4 pm)
- Ensure pH does not drop below 7. If it does then add lime as detailed below.

Responding to high water acidity

- If pH falls below 7 keep monitoring and, if pH remains at or below 7 for 2 to 3 consecutive days, then add lime.
- Either Dolomite or $CaCO_3$ should be used and applied at a rate of 20 kg per ha.
- Lime should be made into slurry with water in a bucket and distributed evenly around the pond.
- The lime should be applied from 8–9 am or in the afternoon at around 5–6 pm.
- Lime will take at least 2 days to dissolve and have an impact on the pH. Therefore pH should be checked 2 days after application of the lime slurry.

Responding to high alkalinity

- When pH is >9 keep monitoring on the days following and, if the pH is still >9 for 2 or 3 consecutive days, then slowly exchange water.
- 20% of pond water volume (10 cm) should be exchanged in 2 stages.

Benthic Algae

- Manual removal of benthic algae growth on the platform is strongly recommended. Chemicals are not effective.

Timing of water exchange

- Water exchange should take place in the late afternoon.
- To maintain water levels water can be taken into the pond when the level drops by 5 cm. Filling should be done slowly from the sediment pond.

Feeding

Feed Type

We recommend that commercial pelleted feeds be used in accordance with the instructions of the feed company. As detailed in chapter 4, there appears to be little nutritional value in feeding shrimp homemade feed with the current formulations. Improved formulations could provide a more nutritionally balanced feed. In developing improved homemade feeds it will be important to ensure that the carbon to nitrogen (C:N) ratio of the feed should be approximately 4:1. The

Mariculture Centre at Cantho University can provide advice on suitable feed contents formulations.

Feed amount per shrimp

- In the first month after shrimp are released from the nursery, feed at a rate of 8% of body weight per day.
- In the second month feed at a rate of 5% of body weight per day.
- In the last month feed at a rate of 3% of body weight per day.

Total feed amount per pond (estimating biomass)

- Feeding should be adjusted depending on the biomass and appetite.
- The two main methods for determining appetite is to use feed trays.
- Biomass can be estimated by using a cast net, providing at least 5 locations around the pond are used. Cast netting should not be done too frequently (once per fortnight is suitable) because of the stress that it can cause to the shrimp.

Feeding frequency

- Feeding should take place 3–4 times per day. 60–65% of feed should be fed at night. Times could be at 5–6 pm and 9–10 pm. Day time feeding should be at 6–7 am with optional feeding between 11 am and 12 pm.
- Two hours before feeding a small amount of feed should be placed on the feed tray. If all the feed is removed after 2 hours then the amount fed can be increased. Likewise, if there is food left, the feed can be decreased below the standard feeding rate of 8% of body weight per day.
- The feed should be distributed by broadcasting around the pond.
- Feeding trays are also useful for monitoring shrimp health (see CTU video).

Health and disease management

Shrimp viral diseases are a major threat to the sustainability of the rice–shrimp system and all other shrimp farming systems in the Mekong Delta. The two most serious and widespread shrimp viral diseases in the Mekong Delta region are White Spot Virus (WSSV) and Yellow Head Virus (YHV). Currently the most effective means of determining whether shrimp are infected with these or other viral pathogens is to screen the shrimp using Polymerase Chain Reaction (PCR) analysis. In the final year of the rice–shrimp project we installed a PCR system at the Mariculture Department at Cantho University and trained staff from the Department to screen for WSSV and YHV. In future we believe PCR technology will be more widely available at hatcheries and at the receiving nursery ponds. This will permit the certification of Specific Pathogen Free (SPF) postlarvae. In the interim, farmers have little choice other than to be vigilant in trying to detect disease outbreaks as soon as they occur. The feeding trays should be closely monitored for signs of weak or dying shrimp. In the event of mass mortalities due to disease the response of the farmers should include the following steps:

Response to mass mortality

- Neighbours and local extension officers should be informed.
- Do not to let the water out of the polder to minimise disease spread to neighbouring farms.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

- Do not rush to restock.
- An important process of sterilisation should be undertaken to reduce the chance of re-infection before restocking takes place.

Sterilisation of the pond can be done as follows:

- Collect all dead shrimp, burn or boil, and dispose.
- The virus can be destroyed in the pond by chlorinating the pond water.

  However, there are a number of constraints to be aware of:
  - — chlorine is ineffective when pH is less than 8
  - — if chlorine is used it should be applied at night because sunlight has a diluting effect on the chemical
  - — concentration levels of less than 15 ppm/30 ppm are ineffective.

Second cropping

Caution should be exercised when considering whether to try for a second shrimp crop following successful harvesting of the first crop or attempts to re-stock after losses to disease. The experience in 2001 was that most farmers tried to produce a second crop of shrimp and delayed the rice crop. Most farmers experienced very high shrimp mortality in the second crop.

Other species

Most rice–shrimp farmers prefer to farm *P. monodon*. However, as described in the technical report, there are usually chronic or severe shortages in the supplies of *P. monodon* postlarvae. In these circumstances farmers can use alternative species. The following are some options:

Shrimp and fish

Dry season: Locally available native shrimp species that are suitable for the rice–shrimp system include *P. merguensis* and *P. indicus*. These should be obtained from a hatchery, particularly hatcheries that have PCR-based health screening capabilities.

Given the shortages in supplies of postlarvae of any native shrimp species a number of hatchery operators have begun to import an exotic shrimp *Litopenaeus* (formerly *Penaeus*) *vannamei* from the Americas. Although this may increase the supplies of postlarvae the risks need to be carefully evaluated. Even if the imported stocks are certified SPF and are free of the specific pathogens detected by screening tests, they do not possess innate resistance or disease tolerance to local viral strains. Furthermore, they may carry as yet unknown viral pathogens that they can tolerate. Native species may be less tolerant and succumb to pathogen, placing the entire rice–shrimp industry at risk. Given the potential to introduce unknown pathogens the imported stocks should be maintained under strict quarantine conditions and their health status assessed for, at least, one generation before they are released for production.

Wet season: Machrobrachium and fresh water fish (tilapia; climbing perch, silver barb). Machrobrachium are known to be carriers of white spot disease, so these stocks should be obtained from hatcheries with PCR screening capabilities.

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
edited by Nigel Preston and Helena Clayton
ACIAR Technical Reports No. 52e
(printed version published in 2003)

Crabs

Crabs, such as the mud crab (*Scyilla serrata*) are an important source of income for many rice–shrimp farmers, particularly when shrimp crops fail. Most shrimp farmers are aware that crabs are predators of shrimp and do not attempt co-stocking. Crabs are also known carriers of white spot and other pathogens. The effects of farming crabs and shrimp in the same location are unknown and possibly benign. Until more information is known, a cautious approach minimizing crab–shrimp interactions is suggested.

Risk management

Diversification and savings

Although the focus of these BMPs has been on the shrimp farming component it is important to re-emphasize that shrimp farming is risky. The results of this study indicate that most rice–shrimp farmers are aware of this. Even with current poor shrimp survival rates, many rice–shrimp farmers are managing their financial risks well by maintaining a generally high level of income diversification at the household level. The importance of a diversified farm household income as a means of managing shrimp income risk was demonstrated in the study (see Chapter 10). An advantage of the rice–shrimp farming system is that income diversification is a natural consequence of the system — the seasonal nature of production results in idle land and/or labour that can be used to earn income from other sources, including agricultural and off farm income. The rice production results in a staple food supply in the event of a poor shrimp crop; this in-kind income is less likely to be "gambled away" in shrimp production, providing food security for the household.

The ACIAR study indicates that most rice–shrimp farmers are aware of the high risks associated with shrimp production and even with current poor shrimp survival rates, are managing their financial risks well by maintaining a generally high level of income diversification at the household level. In addition to the rice crop, other non-shrimp sources of income that can provide an insurance against the risk associated with poor survival of *P. monodon* include upland crops, other aquatic crops, and off-farm income. The stocking density of *P. monodon* is another important factor for farmers to make decisions about in managing income risk in the rice–shrimp system. The maximum stocking rate recommendation from this study is 5–7 PL/m^2. This recommendation is based on both environmental and income risk management objectives. The importance of a diversified farm household income and choice about stocking rates as a means of managing shrimp income risk was demonstrated in the study (see Chapter 10).

Rice–shrimp farming in the Mekong Delta: biophysical and socioeconomic issues
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(printed version published in 2003)