Chapter 8

Socio-economic and environmental implications of inland shrimp farming in the Chao Phraya Delta

Brian W. Szuster, François Molle, Mark Flaherty, and Thippawal Srijantr

8.1 Introduction

Low salinity shrimp farming is a relatively recent development in aquaculture that allows a marine species (the black tiger shrimp *Penaeus Monodon*) to be raised in freshwater inland areas under mesohaline conditions (3–10 ppt). The emergence of low salinity shrimp farming within rice-growing regions of central Thailand has raised concerns regarding potential environmental impacts, and the suitability of conducting this activity within highly productive freshwater agricultural areas. Specific environmental impacts of concern include soil salinisation, water quality degradation as a result of effluent disposal, and water use conflicts with competing activities such as rice farming (Flaherty *et al.*, 2000; Pongnak, 1999). This chapter provides an overview of inland low-salinity shrimp farming in central Thailand. It describes the evolution of this form of aquaculture, discusses husbandry techniques, and examines the controversy over potential environmental impacts. It also compares the economics of tiger shrimp farming in freshwater areas with freshwater shrimp farming and double-cropping paddy rice. For the purpose of this discussion, inland low-salinity tiger shrimp culture in freshwater areas is henceforth referred to as inland shrimp farming.

8.2 Development and evolution of inland shrimp farming

The need for large volumes of brackish water to fill pond enclosures has traditionally limited the cultivation of black tiger shrimp to a relatively narrow band of coastal land within tropical regions. This was certainly the case during the first wave of intensive aquaculture development in central Thailand during the 1980s, when shrimp farms in the Upper Gulf Region were established within the estuaries of the major rivers such as the Chao Phraya, Bang Pakong, Tha Chin, and Mae Klong (see Map 4 in Appendix). Dry season saline intrusion is a common characteristic of these low gradient systems, and the seasonal availability of brackish water within streams and irrigation canals encouraged the construction of a second generation of tiger shrimp farms some distance upstream in areas such as Chachoengsao (Flaherty and Vandergeest, 1998). Brackish water is unavailable in upstream areas during the wet season, however, when higher stream flows counteract tidal influences. Low salinity shrimp culture was originally developed to overcome this limitation and provide a second annual crop (Flaherty *et al.*, 1999). Culture techniques evolved through experimentation led by local shrimp farmers (Chantana, 1993). These individuals discovered that if saline water was trucked-in from the coast when natural supplies of brackish water were unavailable, tiger shrimp post-larvae could be acclimatised to a low-salinity environment (Miller *et al.*, 1999). Although familiarity and availability were the primary reasons for utilising tiger shrimp in these experiments, this species is well known for its tolerance to significant variations in temperature and salinity (Laubier, 1990).

Low salinity shrimp farming expanded rapidly after the technical viability of this culture system was established, and farmers discovered that the high profits derived from shrimp production could easily offset increased costs associated with trucking saltwater from the coast. These factors facilitated the spread of inland shrimp farming into freshwater agricultural areas that never experience seasonal saltwater intrusion. Farms that draw freshwater from the existing rice irrigation infrastructure, and purchase saline water from tanker truck operators, now exist hundreds of kilometres from the coast, in areas such as the provinces of Prachin Buri, Suphan Buri, Nakhon Pathom, and Nakhon Nayok (Department of Land Development, 1999a).

The development of shrimp farming in freshwater areas was also hastened by on-going problems with water-borne viral disease outbreaks (e.g., white sport virus, yellow head) that substantially reduced production in coastal shrimp farming areas. Poor environmental conditions along the coast, combined with the susceptibility of coastal shrimp farms to disease, led some analysts to predict that overall Thai farmed shrimp production may decline (Dierberg and Kiattisimkul, 1996). However, with the development of low salinity shrimp culture techniques, farmers no longer required direct access to contaminated coastal waters.

Development opportunities are limited only by basic site suitability criteria (e.g., relatively flat land and a reliable source of freshwater), saltwater transportation expenses, and land leasing costs (Flaherty and Vandergeest, 1998). Inland shrimp farming represented as much as 40% of Thailand's total cultured shrimp production by late 1998 (Limsuwan, 1998), and an inventory conducted during this period by the Department of Land Development identified 140,343 *rai* of land devoted to inland shrimp farming in the central region (Table 8.1).

Table 8.1 Inland shrimp farms in the central region of Thailand

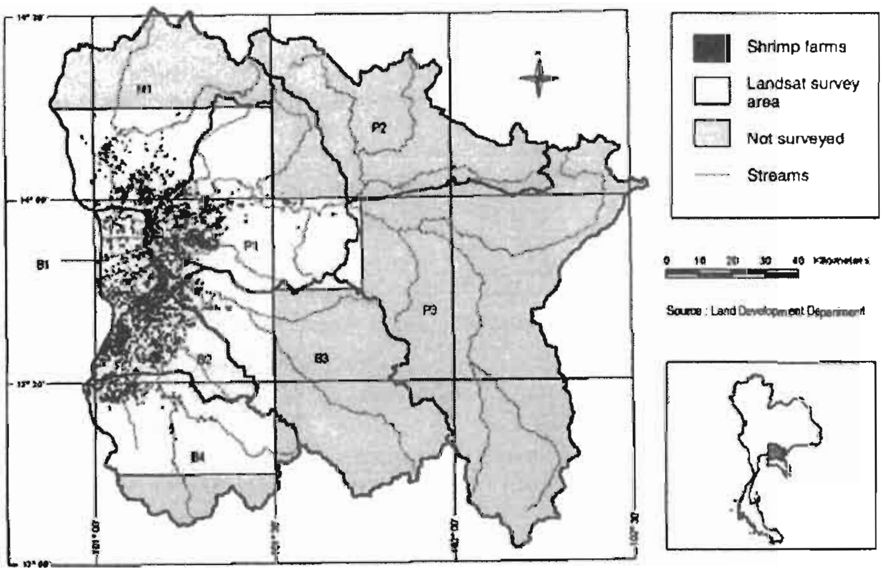
Province	Area (*rai*)	Province	Area (*rai*)
Chachoengsao	52,346	Ang Thong	1,205
Prachin Buri	28,608	Khrung Thep	321
Nakhon Pathom	13,775	Lop Buri	300
Nakhon Nayok	10,947	Chai Nat	290
Chon Buri	10,193	Nakhon Sawan	275
Suphan Buri	8,491	Nonthaburi	139
Samut Prakan	3,240	Kanchanaburi	120
Ayutthaya	2,816	Saraburi	97
Ratchaburi	2,186	Sing Buri	78
Phetchaburi	2,010	Uthai Thani	63
Pathum Thani	1,525	Samut Songkhram	30
Samut Sakhon	1,288		

Source: Department of Land Development, 1999a.

The expansion of inland shrimp farming into Thailand's irrigated rice growing areas was halted in 1998 when the Royal Thai Government banned inland shrimp farming in all freshwater provinces on the basis of a recommendation from the National Environment Board (Srivalo, 1998). Governors in coastal provinces were subsequently instructed to designate land within these areas as freshwater (where shrimp farming would be banned) or brackish water (where shrimp farming could continue). A joint committee including representative of the Departments of Land Development, Pollution Control, and Fisheries is also currently considering the fate of inland shrimp farming in seasonally brackish areas such as the Bang Pakong River Basin (Figure 8.1) that are not easily classified using this approach.

The Bang Pakong River Basin includes portions of Chachoengsao, Prachin Buri, Chon Buri, and Nakhon Nayok provinces. The joint committee has submitted a report and recommendations to the Thai government for consideration, and a decision on the fate of inland shrimp farming in the Bang Pakong River Basin is expected during 2001.

Figure 8.1 Shrimp farms along the lower Bang Pakong River



Source : Land Development Department

In spite of the prohibition on shrimp farming within freshwater provinces over the past 2 years, concerns continue to exist over the capacity of the Thai government to enforce the ban, the manner in which brackish water and freshwater areas have been designated, and the possibility that the ban on inland shrimp farming could be relaxed (Flaherty *et al.*, 2000). These concerns are reinforced by several factors. Shrimp farming plays an important role in the Thai economy, with sales to the United States, Europe, and Japan earning approximately US$ 2 billion in export revenue during 1999 (*Bangkok Post*, 2000a). The Thai government has also been a staunch supporter of shrimp farming, and is presently encouraging farmers to raise more shrimp so as to offset a worldwide shortfall caused by disease outbreaks in

Latin America (ibid.). Although there may be some potential for increasing shrimp production through the intensification of existing farms, this strategy is accompanied by a higher risk of disease outbreaks and crop failure. It is likely, therefore, that increased production will require additional pond area which will be supplied by new operators entering the industry and/or existing farmers expanding their operations. With the further development of shrimp farming in Thailand's coastal areas increasingly constrained by high land values, more effective protection of mangrove forests, and concerns over the risk of disease owing to poor environmental conditions (Dierberg and Kiattisimkul, 1996; Vandergeest *et al.*, 1999), renewed pressure is likely to develop for the expansion of shrimp farming into freshwater areas (*Bangkok Post*, 2000b).

8.3 Husbandry and operating procedures

Inland shrimp farming practices are similar to those used in typical coastal operations which feature high stocking densities, aerated ponds, and a reliance on pelletised feeds, fertilisers, and chemo-therapeutants. The primary difference is that while coastal farms use naturally occurring seawater (15–30 ppt) to fill and replenish pond enclosures, inland farms combine freshwater with saltwater purchased from coastal salt pans or saltwater concentrate operations. This approach achieves an initial pond salinity level between 4 and 10 ppt. Further freshwater inputs are subsequently used to offset evaporation and seepage losses, and this process can reduce pond salinity levels to nearly zero by the time of harvest unless supplementary salt is applied (e.g., trucked saline water or bagged salt). Even though naturally occurring brackish water is seasonally available in some areas of the central plains region during the dry season (e.g., Bang Pakong River Basin), few inland shrimp farms will use this supply source due to the potential presence of viral pathogens and other contaminants such as pesticides (Ponza, 1999).

Thailand's transition from a small-scale producer into the world's largest exporter of cultured shrimp has been facilitated by the development of over 1,500 small-scale "backyard" hatcheries (Kongkeo, 1994). A substantial low-salinity hatchery sector has developed in provinces such as Chachoengsao and Chon Buri to support the inland shrimp farms, and these operations have made several adaptations to produce shrimp at the post-larvae (PL) stage of development that are acclimatised to a lower than normal salinity. Acclimation begins during the early post-larval stages in fry rearing tanks containing full strength seawater. Over a period of three to five days, salinity levels are gradually reduced from 30 ppt to

10 ppt by adding freshwater. The PL are ready for sale and delivery to farms when they are 12 to 15 days old.

A variety of methods is used to continue the acclimation process after the PL are delivered to the farm site (Miller *et al.*, 1999; Ponza, 1999). The simplest method involves slowly mixing water contained in the PL transport packages with pond water until a salinity similar to the grow-out environment is achieved. A second technique involves maintaining the PL in a separate nursery pond for 45–60 days where they are acclimatised to lower salinity levels. The PL are then transferred to the larger grow-out pond by means of lift or bag nets. However, the most common PL acclimation method is the use of a small PVC or earthen bund nursery pen constructed within the grow-out pond. In this approach, the grow-out pond is initially filled with freshwater to a depth of 30 to 80 centimeters, and saltwater is pumped into the nursery pen. For a typical 0.6 hectare grow-out pond using the nursery pen method, two 15 metric tonne truck loads of 60 ppt water are required to raise the salinity of the nursery pen water to approximately 10 ppt (Miller *et al.*, 1999). Sections of the plastic PVC paneling or bund are removed over the first 7 to 10 days and replaced with mesh to allow the saline pen water to slowly mix with freshwater in the rest of the grow-out pond. The PL are released from the nursery pen into the full grow-out pond after the acclimation period is complete. Salinity in the full grow-out pond can range from 3 to 8 ppt at the end of the acclimation period depending on a variety of factors including pen size, water depth, and initial salinity levels.

Freshwater is generally added to the grow-out pond at a rate of 5 to 10 cm every 10 days during the grow-out period until a maximum pond water depth of 1.3 to 1.5 metres is achieved. The use of reservoirs to enhance water management during the grow-out period is becoming more common, but these facilities can only be constructed on farms with adequate land holdings and the farmer must be willing to sacrifice production area (Flaherty *et al.*, 2000). Reservoirs act as a buffer between water sources that contain disease pathogens or surface water pollutants, and can serve as receptacles for nutrient enriched harvest effluent. They are used to allow sediment to settle out of canal water before being added to the ponds, and reservoirs encircling the production ponds can also reduce saline water intrusion to adjacent rice paddies. The most common and simple reservoir system is a water ditch barrier between shrimp ponds and surrounding rice paddies.

The standard grow-out period for inland culture systems is a relatively short 100–120 days. Harvest at inland farms occurs earlier than in most coastal operations as a result of decreasing salinity levels and the negative effect this has on shrimp health and development. Shrimp produced by inland farms average 50 pieces per kilogram at harvest (Ponza, 1999; Miller *et al.*, 1999) which is quite small in comparison to coastal operations. Prices vary widely from crop to crop owing to international market fluctuations, but a typical price during the year 2000 for small shrimp sized at 50 pieces per kilogram was approximately US$ 10 per kilogram (Shrimp World Incorporated, 2000). Although yields vary greatly between operations, a successful inland shrimp farm can produce five metric tonnes per hectare twice a year. Assuming the current farm gate price for small shrimp, a farmer with one hectare of his holdings devoted to shrimp culture would have a gross annual income of US$ 100,000 (based on two crops). This is at least 25 times the income of a typical rice farmer in central Thailand, and illustrates how lucrative shrimp farming can be compared to rice cultivation. It also explains why rice farmers who can raise the investment capital are willing to take a gamble on raising shrimp (see Section 4). In cases where rice farmers are unwilling or unable to invest themselves, there is ample opportunity for leasing paddy land to outside investors at rents that greatly exceed what they could obtain growing rice. Although that income estimate does not take into account the significant capital costs associated with pond construction, farm infrastructure such as pumps and aerators, and feed, successful shrimp farmers can commonly recoup their initial investment within one year. This assumes, of course, that they do not experience catastrophic disease problems which can lead to crop failures.

8.4 Socio-economic aspects

Perhaps the most important factor contributing to the diversification out of rice and into shrimp farming is the large gap in land productivity. In accordance with the general association between income and risk in agriculture, shrimp farming is also a much more risky undertaking. This section compares the average incomes provided by tiger prawn farming (KD, or *kula dam*), macrobrachium (freshwater) shrimp farming (KK, or *kram kram*), and rice double cropping. It then undertakes to assess the sensitivity of each activity to risk, both agronomic and economic.

8.4.1 Comparison of average incomes

The production costs of shrimp farming are not uniform across farms. Although following a similar husbandry technique, there are distinct differences in the degree of intensification of this activity. This is reflected in the different management decisions made regarding such factors as stocking density (generally between 80,000 and 140,000 shrimp/*rai*), method of pond preparation, feeding practices, use of chemotherapeutants, and the frequency of water aeration. Yields are highly affected by the quality of PL, the quality of water, and/or the occurrence of disease. Also the sale price is subject to the vagaries of the market. The following calculations are based on average values relative to the development of shrimp farming in the Bang Len area[1] (upper Nakhon Pathom province). Prices are taken as the deflated historical average over the past ten years and yields reflect average production levels in the absence of severe yield-reducing factors. Rice production costs are computed for a farmer who prepares the land himself, hires labour to apply chemicals, and harvests by machine.

Several striking differences between the three activities are apparent. First is the level of production costs (Table 8.2; Figure 8.2). While rice production requires approximately 1,300 baht/*rai*, shrimp farming requires a capital input of 51,000 baht for KK shrimp and almost twice that amount for KD shrimp. The bulk of these costs represents feed, shrimp PL, and gasoline. Despite being labour intensive (one person is required to regularly check water quality, distribute feed, pump water, etc.) a single worker can care for 4–5 *rai* of KD shrimp or over 10 *rai* of KK shrimp. The former is more intensive in care (feeding 4–6 times a day, stricter control of water quality, etc) than the latter. Additional labour is required only at harvest when a group of 10 to 25 labourers is hired by the day. Only 18% of the farms surveyed employed permanent labourers.

Also striking are the relatively low fixed costs associated with shrimp farming. Starting a shrimp farm requires that the paddy field be transformed into a pond. A mechanical excavator (*makro*) is used to cut the soil surface to a depth of 35 cm for KK ponds and 50 cm for KD ponds (these values may vary depending on the plot size and topography). The earth is then pushed to the sides by a bulldozer to form a surrounding dike. Thanks to the large fleet of excavators, bulldozers, and tractors in the delta, where earth moving has long been an important activity, such operations are relatively inexpensive. Other investments include axial pumps and motors (for which an active second hand market exists) and water aerators. This brings the initial investment for a KD shrimp farm to approximately 45,000 baht/*rai*, and less than half of this amount for a KK shrimp farm. However, these values, multiplied by a few *rai*, are generally beyond the investment capacity of most rice farmers.

Table 8.2 shows that the yearly income per *rai* is slightly over 4,000 baht for rice and that KK and KD shrimps deliver a much higher level (13 and 35 times

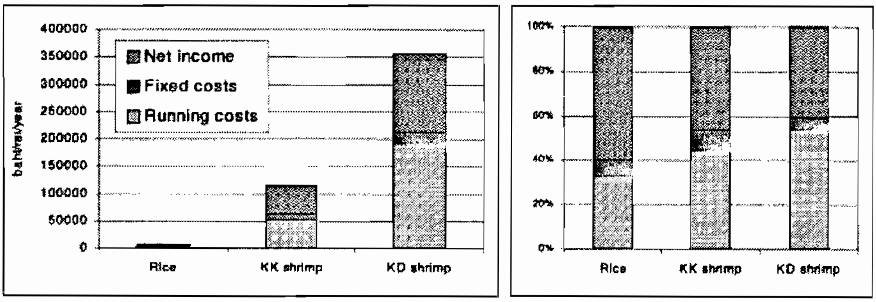
Table 8.2 Production costs and income per *rai* of rice and shrimp (baht)

Rice	HYV	Shrimps	Macrobracium Kram Kram	Tiger Prawns Kula Dam
Land preparation	93	Shrimp fries	8,324	15,637
Seeds	90	Saltwater	0	7,482
Fertiliser	105	Pond preparation	1,102	4,592
Herbicide	110	Food	26,850	44,907
Pesticide	90	Medicine	3,522	5,913
Spray	70	Gasoline/electricity	5,976	11,035
Gasoline (pump)	200	Pond cleaning	2,127	2,527
Maintenance		Labour	2,295	2,332
Harvest	300	Transportation	885	1,093
Transportation	100	Other	126	740
Running costs	1,158	Running costs	51,207	96,258
Two wheel tractor	50	Pond excavation	295	332
Cart	10	Pumps/motors	907	1,274
Pump	10	Hut	167	83
Sprayer	10	Water aerators	55	893
Levelling	12	Other	60	0
Fixed costs	92	Fixed costs*	1,484	2,582
Interest		Interest	9,348	7,193
Land rental	167	Land rental	0	0
Yield (kg/rai)	700	Yield (kg/rai)	480	890
Price (baht/kilo)	5	Price (baht/kilo)	240	200
Gross product	3,500	Gross product	115200	178,000
Net value added	2,250	Net value added	62510	79,160
Net income/rai/crop	2,083	Net income/rai/crop	53,162	71,967
Cropping intensity	2	Cropping intensity	1	2,0
Net income/rai/year	4,166	Net income/rai/year	53,162	143,935
Costs in % net V.A	36		46	56
Net income/running costs	1,8		1,0	0,7
Net income/fixed costs	22,6		35,8	27,9
Net income/total costs	1,7		1,0	0,7

* Fixed costs are distributed over the number of crops over 10 years (and 6 years for water aerators).

more respectively). These average incomes per *rai* must be multiplied by the size of the farm. In our sample, the average farm size was 13.8 *rai*, with a much lower value for KD (7.9 *rai*) than for KK (14.8 *rai*), which reflects the differences in investment and risk. The corresponding incomes are obviously beyond what rice farmers have ever dreamt of. Generally, in cases of poor yields and/or poor marketing, the risk of going into debt is extremely high.

Figure 8.2 Costs and net income of the three activities



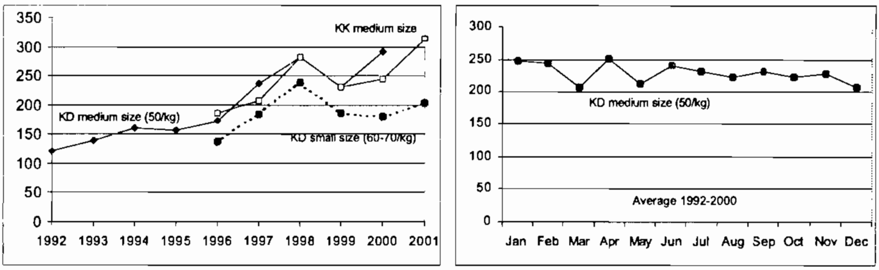
8.4.2 Shrimp farming and risk

As a rule, agricultural activities with higher potential profitability are also more risky. In the present case, risk is defined both by the sensitivity of shrimp to disease and by fluctuations in market prices. A total of 62% of farmers in our sample reported having experienced years with drastic production losses. Most of the time this was attributed to "disease" but other causes included poor water quality, cold weather, lack of experience, soil quality, and crop theft. A good production of KD shrimp can yield 1 tonne/*rai* or more, but yields can also come down to 400 kg/*rai*, or even zero.

Diseases or poor shrimp development have an impact not only on yields, but also on shrimp size. One kilo may contain between 20 to 100 shrimp, and the price varies accordingly. For these two extreme values, the ratio of the price averages over the last 10 years was around four. Figure 8.3 shows that KD prices have appreciated greatly over the last decade, and that monthly variations have not been as high. It can be concluded that this rise in prices has been a strong incentive in the decision to adopt shrimp farming. So far, the control of water quality and sanitary conditions have been much more severe problems for farmers than price fluctuations. However with the spread of shrimp production into many countries it is likely that more uncertainty lies ahead.

Risk in shrimp farming originates from the uncertainty on these two factors, coupled with the low ratio of net income to production costs (0.6 for KK and 0.2 for KD shrimps) or, in other words, to the high share of costs relatively to the value added. The cost/value added ratio is 36% for rice, 62% for FD shrimp, and 83% for KK shrimp.

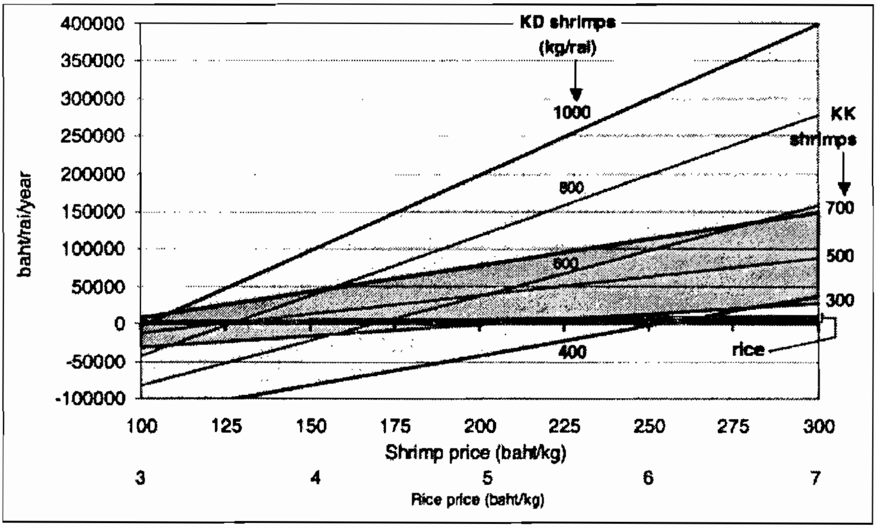
Figure 8.3 Yearly and monthly price variations



We now consider the "risk ranges" of the three activities in more detail. Figure 8.4 plots their net income, relative to a commonly observed range of yields and output prices (x axis). Even for extreme yields (500 kg/*rai*) and prices (3 baht/kg), the rice income remains positive (in red; this is not clearly visible because of the scale). KK shrimp farming shows a limited (price, yield) area (in blue) where income turns negative but can hardly exceed 150,000 baht/*rai*. In contrast, KD shrimp farming can soar to extremely high incomes (several hundreds of thousands baht/*rai*) but also exhibits a rather wide (price, yield) area (in grey) with negative economic gains. Figure 8.4 readily illustrates the differences between the three activities in terms of profit and risk.

Another risk limiting strategy that illustrates the management trade-offs considered by shrimp farmers deserves mention. KD shrimp farmers commonly apply very high PL stocking density (often over 100,000/*rai*) and harvest after a relatively short 3–4 month grow-out period. This strategy reduces the risk of disease-related losses and limits feed costs, but produces only small sized shrimp (60 pieces per kg). KD farmers could adopt lower stocking densities and a longer grow-out period to produce larger shrimp, but they appear to prefer a risk limiting approach as the income obtained by this strategy is still extremely attractive.

Figure 8.4 Rice and shrimp income sensitivity to yield and price changes



However, experience from coastal shrimp farming areas in Thailand suggests that the use of high PL stocking densities ultimately increases the likelihood of disease outbreaks. Decreasing the short-term risk of a single crop failure by applying a high PL stocking ratio may, therefore, increase the long term risk of total farm failure as a result of the ecological unsustainability of this technique.

8.4.3 Who enters shrimp farming?

Risk together with the possible economic benefits are paramount factors in the decision to begin shrimp farming. With potential yearly net benefits running between 13 to 35 times that of rice, it is no wonder that rice farmers are tempted to gamble and try to earn in two or three years what would otherwise be a lifetime income. This raises the questions of who is most likely to engage in shrimp farming, and why some farmers refrain from doing so. Our sample of 106 shrimp farms was supplemented by a survey of 35 farmers who grow rice in the close vicinity of shrimp farms (Table 8.3).

Risk taking is often positively correlated with a farmer's age. Although the samples are limited, it is interesting to note that the average age for rice, KK and

KD farmers was 49, 44, and 39 years respectively. Average family sizes were also comparable (5.2 for rice, 5.4 for shrimp), and suggest that labour availability is not a drastic constraint. Many of the larger farms found in the area employ permanent labourers who, in many cases, are underpaid Burmese migrants. To offset the expected low degree of commitment and care from these labourers, farm owners generally make part of their remuneration proportional to the production achieved. On 92% of the farms, the landowner (or renter) is also the farm manager. He is commonly helped by his wife (72%) or by a child/relative (36%). Consequently, the level of outside employment is very low (4% of farmers and 10% of their wives have off-farm activities) which indicates that shrimp farming is a highly demanding activity in terms of daily care.

Table 8.3 Characteristics of the shrimp farm sample

Start of operation	Before 1990	1991–95	1996–98	1999–2001
% of farms	13	39	32	13
Age of farmer	Under 30	31 to 40	41 to 50	Over 50
% of farms	18	32	26	24
Farm size	Under 5 *rai*	5 to 10 *rai*	10 to 20 *rai*	Over 20 *rai*
% of farms	18	32	26	24

Access to land does not appear to be a drastic constraint, which suggests that the rise in land rents (typically from 450 baht/*rai* for rice to 1,500 for KK and 4,000 for KD) is sufficient for the landowner to offset the cost of having his land excavated and/or salinised. Rental contracts are generally made for 3 years or more, and no contractual precariousness, which would deter investment, was reported. Farm managers own 79% of the total pond area, against 21% for rented ones. Also noteworthy is the fact that while the rice farms have an average area of 36 *rai*, the shrimp farms have only half as much average area.

Access to capital may also be a constraint to start shrimp farming. A total of 58% farmers invested their own capital, 55% borrowed from banks (generally the Bank of Agriculture and Agricultural Cooperatives)[2], 14% from relatives, 11% from neighbours, and only 5% from middlemen. However, 40% of the farmers relied on two or more sources of credit (hence the total is over 100%). Regarding production running costs, 67% use their own capital but 61% made contractual arrangements with suppliers to pay for their inputs after harvest. Only 23% resorted to banks.

Another issue concerned the occupation of shrimp farmers before engaging in shrimp raising. In this survey, 73% were rice growers (9% with additional non-rice crops), 12% grew sugarcane or fruit trees, while 14% were non-farmers. There was a range of diversity among the non-farmers who had become shrimp farmers. Previous occupations reported included student, truck driver, merchant, and gas station manager.

The overall picture is that the profitability of shrimp production attracts all kinds of investors (farmers and non-farmers), and that factor constraints are not critical. Among the reasons given by 20 neighbouring rice farmers for not engaging in shrimp farming, lack of capital ranked first (13), which may reflect either the lack of credit sources or the fear of resorting to them. Other reasons include risk aversion (6), poor water quality (5), lack of time (4), opposition of the landowner (4), unsuitable land holdings (2), lack of skill (2), and failure by relatives (2). It is noteworthy that lack of skill, which is often a deterrent to the adoption of innovations, is given so little weight. The shift from rice to shrimp farming is, therefore, favoured by relatively good water conditions in the area, the absence of critical shortages of land and labour, and relatively abundant capital. Risk is generally tackled by first shifting from rice to KK shrimp farming, and only later to KD when experience and capital have been accumulated (77% of the KD farms raised KK before).

8.5 Environmental impacts

The ban on inland shrimp farming initiated a heated debate over the nature and significance of the environmental impact. Inland shrimp farmers were outraged at the imposition of the ban on their activities in freshwater areas, and argued that it was founded on biased environmental impact assessment information (*Bangkok Post*, 1998). Specific issues of dispute are the potential for salinisation of agricultural soils, water pollution stemming from the discharge of pond effluents, and competition between agriculture and aquaculture for freshwater supplies.

8.5.1 Soil salinisation

Salinisation can occur directly through the deposition and accumulation of salts in soils located immediately beneath the pond enclosure, or indirectly as a result of seepage into adjacent agricultural areas. Indirect salinisation impacts could also be produced through the disposal of saline effluents into streams or irrigation canals which are subsequently used to irrigate rice paddies or orchards.

The most recent estimate of land subject to direct salinisation impacts as a result of inland shrimp farming in the central region is 22,455 hectares (Table 8.1) and we estimate salt loading to be roughly 2.7 metric tonnes per hectare per crop. This value assumes that 3 truckloads (15 metric tonnes each) of saltwater at 60 ppt are required for each hectare of inland shrimp pond. Since almost all farms produce two crops per year, annual salt inputs would be 5.4 metric tonnes per hectare per year. The use of PL nursery pens reduces overall salt requirements, but this approach is not universal and salt inputs are substantially higher on farms that maintain pond salinity levels of 10 ppt throughout the grow-out period. This estimate also does not consider the common practice of adding bagged salt during the grow-out period to maintain salinity. Given these factors, a 5.4 metric tonnes per hectare annual salt loading figure should be considered conservative.

The significance and extent of indirect soil salinisation effects are, however, much more difficult to assess. Recent studies conducted by the Thai Ministry of Science and Technology (1999) suggest that seepage can increase salinity in soils from 50 to 100 meters from the edge of inland shrimp ponds. Caution must be exercised in assessing the amount of land actually affected by indirect impacts because impact pathways are extremely complex and mitigating factors exist (e.g., natural soil flushing by monsoon rains). Given the size and agricultural importance of the areas potentially affected, however, the significance of direct and indirect soil salinisation impacts should not be underestimated. Much of the land converted to shrimp ponds was highly productive rice paddies, and the cost of returning this land to agricultural production if shrimp farming fails could be substantial (Land Development Department, 1999b).

8.5.2 Water pollution

While water quality problems are common in all shrimp farming areas, these can be especially problematic in inland regions where small streams and irrigation canals possess a relatively low assimilative capacity. The majority of the nutrients added to shrimp ponds in the form of fertiliser or pelletised feed are not incorporated into the shrimp, but end up being deposited in pond sediments or discharged as effluent (Funge-Smith and Briggs, 1998; Tookwinas, 1997). Most small inland shrimp farms ponds completely drain grow-out ponds at harvest, and release large quantities of untreated effluent directly into adjacent water bodies. Only a relatively small number of large operations treat and recycle effluent within holding reservoirs. The decomposition of organic waste in surface waters reduces dissolved oxygen levels, can suffocate or smother aquatic fauna, and produces toxic chemicals such as ammonia and hydrogen sulphide (Primavera, 1998).

Inland shrimp farms operate somewhat differently than coastal operations, as very little effluent is released during the first 60 days of the grow-out cycle (Braaten and Flaherty, 2000). Feed requirements are relatively modest at this point, and additions of freshwater are usually sufficient to maintain water quality in the pond. During the latter half of the culture cycle, however, water exchange is used to maintain the growing environment and effluent is discharged. A significant amount of nutrient enriched effluent is also released during harvest when the ponds are completely drained. Very little information is available on the composition and impact of inland shrimp farm effluent, but it has been estimated that culture period and harvest effluent contain BOD concentrations of between 10 and 25 milligrams per litre (Pollution Control Department, 1996; Ingthanjitr, 1999). Although the effect of shrimp farm effluent on receiving waters is of concern, a much more serious issue exists with regard to the disposal of semi-liquid sludge that remains in the grow-out ponds after harvest. This material consists of uneaten feed, faeces, and sediments eroded from the pond enclosure (Funge-Smith and Briggs, 1998) and is highly polluting with BOD concentrations of 1,500 milligrams per litre or higher. Pumping pond sludge directly into adjacent water bodies is illegal, and this material is usually maintained on site in holding ponds or packed onto pond banks. The illegal dumping of pond sludge into freshwater bodies is not uncommon, however, due to a lack of farmer awareness and regulatory enforcement (Pollution Control Department, 1996; Braaten and Flaherty, 2000).

Other important water pollutants originating in shrimp ponds are the chemotherapeutant products added to ponds by the farmers. These chemicals can leave the ponds through effluent, seepage through pond bottoms, and through the removal and disposal of bottom sludge. One of the most common and worrisome pond additives is antibiotics. Most commercial shrimp feeds are enriched with common antibiotics such as oxytetracycline. Studies of fish farms have shown that the majority of antibiotics added in feed are not assimilated by fish but go into the environment (Weston, 1996). Once in the environment, antibiotics can have a wide range of effects. In surface water, they may lead to antibiotic resistant pathogens or accumulate in the tissues of wild fish. If they accumulate in sediments, antibiotics may prevent natural bacterial decomposition and consequently alter the natural benthic environment (Chua *et al.*, 1989).

8.5.3 Water use conflicts

It is not surprising that inland shrimp farming evolved within traditional rice growing areas of Thailand, as the activity requires substantial quantities of fresh water to fill pond enclosures and maintain environmental conditions during the grow-out period. The presence of plentiful freshwater supplies is critical to the success of inland shrimp farming, and irrigation infrastructure originally developed for rice cultivation is easily adapted to aquaculture. Water use impacts associated with shrimp farming typically involve excessive consumption or competition between rice and shrimp farmers for limited supplies (Miller *et al.*, 1999).

Although limited information is available on inland shrimp farm water use, a recent study has been completed on this topic (Braaten and Flaherty, 2000). This study found that a typical inland shrimp farm withdraws approximately 18,700 m^3 of water per hectare per crop per year, and consumes approximately 9,050 m^3 per hectare per crop. This consumption figure is roughly similar to other crops grown within irrigated regions of Thailand (e.g., wet rice, banana, or sugarcane) and suggests that inland shrimp farming should not have a significant impact on water use. In non-irrigated areas, however, inland shrimp farming may still have the potential to aggravate existing water use conflicts. The dry season is the optimum period for raising shrimp, and this preference may increase freshwater demand during a period of limited supply. Dry season demand for freshwater may even increase in areas that have saltwater naturally available as a result of intrusion, because shrimp farmers generally avoid this water source due to concerns over quality and virus transference. Water use conflicts are also possible as a result of groundwater pumping. A ban on groundwater pumping for aquaculture purposes has been imposed in coastal areas of Thailand to prevent subsidence and protect agricultural and domestic water supplies, but the prevalence of this practice in the inland shrimp farming sector is currently unknown.

8.6 Conclusions

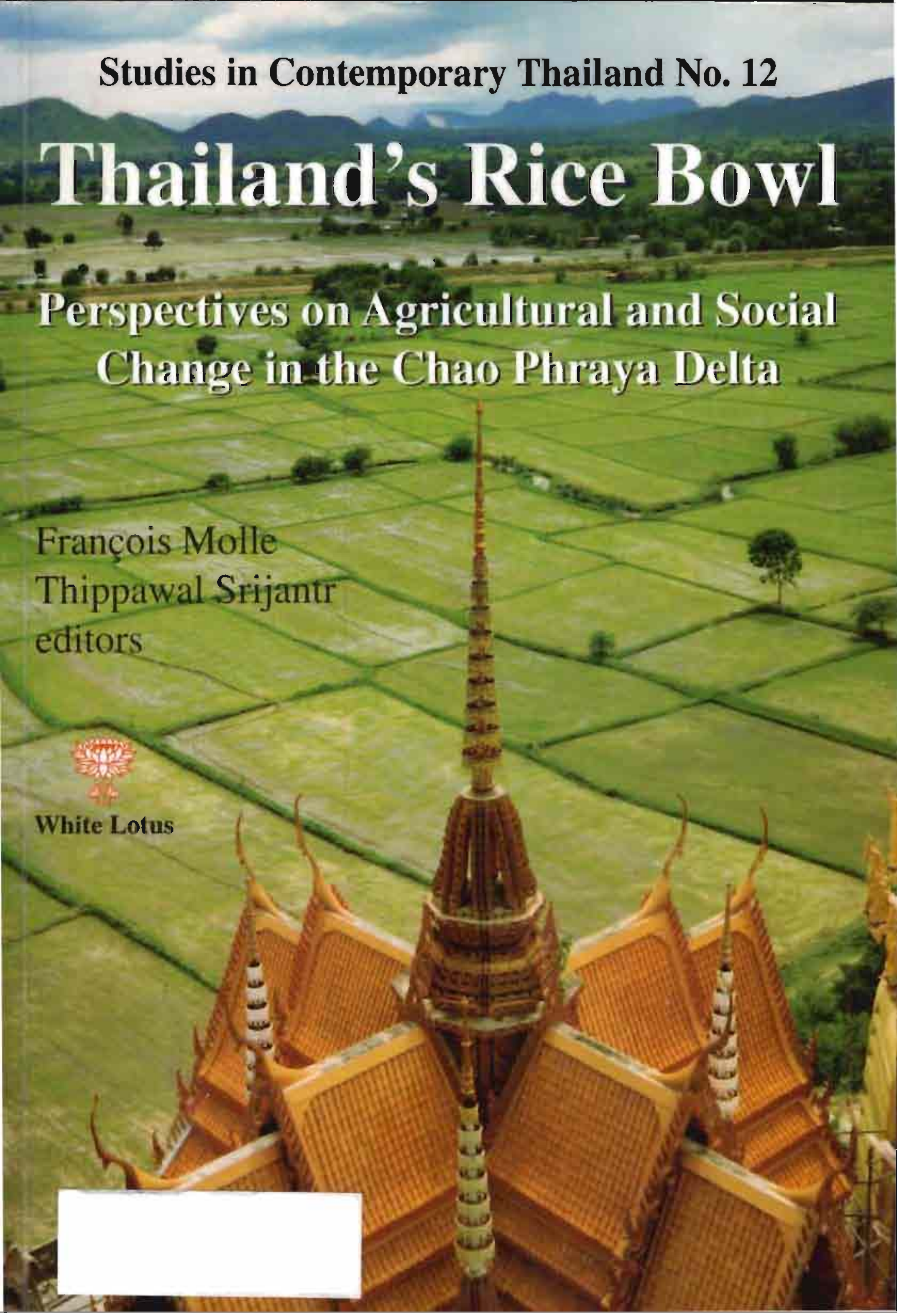
Inland shrimp farming presents a situation where significant short-term economic benefits may be obtained, but at the risk of going bankrupt and of creating significant environmental impacts. Of the impacts discussed above, soil salinisation is clearly the most critical issue due to the potential for inland shrimp farming to cause long term damage to agricultural areas which may be difficult and expensive to reverse (Ministry of Science and Technology, 1999). Cumulative effects are a second area of concern. Although many inland low salinity shrimp farms are less than 1 hectare in size, the existing magnitude and density of development in many areas may have the potential to degrade regional soil and water resources (Flaherty *et al.*, 2000). Cumulative effects represent the additive or inter-active effects of multiple small-scale activities (such as shrimp farming) on larger ecological units such as watersheds. Although the short-term impact of an individual inland shrimp farm on regional environmental quality is likely to be limited or negligible, the long-term cumulative effect of a large number of inland shrimp operations on regional soil and water conditions may be substantial due to the slow accumulation of salt and other waste products.

Current studies into the environmental impact of inland shrimp farming in Thailand are focusing on the site-specific effects of individual operations. Although these studies will undoubtedly increase our understanding of specific environmental concerns, this approach cannot address the potential cumulative effects produced by large numbers of inland shrimps farms operating in dense concentrations. If inland shrimp farming continues in some form within Thailand, we believe that research into the long-term regional implications of this activity must be undertaken to insure the security of soil and water quality in Thailand's agricultural heartland.

8.7 Notes

[1] A sample of 106 farms was surveyed in *amphoe* Bang Len (predominantly in *tambon* Sra Simum, Don Khoi, and Sra Patthana), including KK shrimp farms (73), KD shrimp farms (32), and mixed KK/KD farms (14).

[2] Unexpectedly, this rate is almost unchanged (50%) for full tenant farm managers.



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François Molle
Thippawal Srijantr
editors

White Lotus

Francois Molle and Thippawal Srijantr are affiliated to, respectively:

Institut de Recherche pour le Developpement (IRD); 213 rue Lafayette 75480 - Paris CEDEX 10, France. Website: www.ird.fr

Kasetsart University; 50 Phahonyothin Road, Chatuchak, Bangkok, 10900, Thailand. Website: www.ku.ac.th

White Lotus Co., Ltd.
GPO Box 1141
Bangkok 10511
Thailand

Telephone: (662) 332-4915 and (662) 741-6288-9
Fax: (662) 741-6607 and (662) 741-6287
E-mail: ande@loxinfo.co.th
Website: http://thailine.com/lotus

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