CASE STUDY 6.5

RISK ANALYSIS OF THE SOIL SALINIZATION DUE TO LOW-SALINITY SHRIMP FARMING IN CENTRAL PLAIN OF THAILAND

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6.5.1 Introduction

In Thailand, commercial shrimp farming such as the farming of tiger shrimp (*Penaeus monodon* - Figure 1) was first concentrated in coastal mangrove areas of the provinces (for example, Samut Sakorn, Samut Songkram and Samut Prakan) along the upper Gulf of Thailand; this region accounted for more than 40% of the country's total shrimp farming area (Boromthanarat and Nissapa 2000). During the market boom in 1990s, shrimp farming in Thailand expanded very rapidly into areas along the southwestern coast adjacent to the Andaman Sea (Smith 1999) and later into the Chao Phraya Delta as well as the eastern part of Thailand (Lindberg and Nylander 2001; Szuster 2003a). As a result of the rapid expansion in farming areas, production of farmed shrimp in Thailand significantly exceeded that for captured shrimp : in 2003, 330,000 tonnes for farmed shrimp, compared to 67,000 tonnes for captured shrimp (DOF 2004).

Like many countries in the tropics, rapid growth of shrimp farming in Thailand during the last two decades has given rise to numerous adverse environmental changes which include:

a) Loss of mangrove habitat that used to be the nursery grounds for larval shrimp and fish as
b) Eutrophication of coastal areas due to the presence of excessive nutrients in the effluents discharged from shrimp ponds;
c) Salt water intrusion into the water table of nearby agricultural land and land subsidence due to over-extraction of both fresh and brackish groundwater to reduce the water salinity in coastal shrimp ponds; and
d) Increased turbidity in receiving waters due to uncontrolled discharge of pond sediments from the surrounding shrimp farms (Boyd and Musig 1992; Avault 1993).

Among these changes, the loss of mangrove forests has received the most attention due to the advocacy and scrutiny of international non-government organisations (NGO's). Thus, in the early 1990s, following the discovery that shrimp farming destroyed mangrove forest areas, the Thai government imposed a ban on the further development of shrimp farms in coastal mangrove areas. To cope with the problem that only limited coastal mangrove areas are now available for shrimp farming in saline water due to the ban, low-salinity shrimp farming techniques were developed as shrimp farmers discovered that black tiger shrimp (Figure 6.5.1) post-larvae could be acclimatised to grow in low salinity environments (Szuster and Flaherty 2000). The farming techniques, which involve mixing high salinity water with fresh water to give a final salinity to as low as 3-5 part per thousand (ppt), have also been proven to be technically and economically viable. The low-salinity farming techniques were found to provide the opportunity for producing two or even three crops of shrimp per year and thus developed rapidly. As a result, low-salinity shrimp farms were found in inland areas as far as 200 km from the Gulf of Thailand, covering large areas of completely freshwater agricultural land deep inside the Central Plain region (for example, in the provinces of Lopburi, Isingburi and Ang Thong) (Figure 6.5.2).

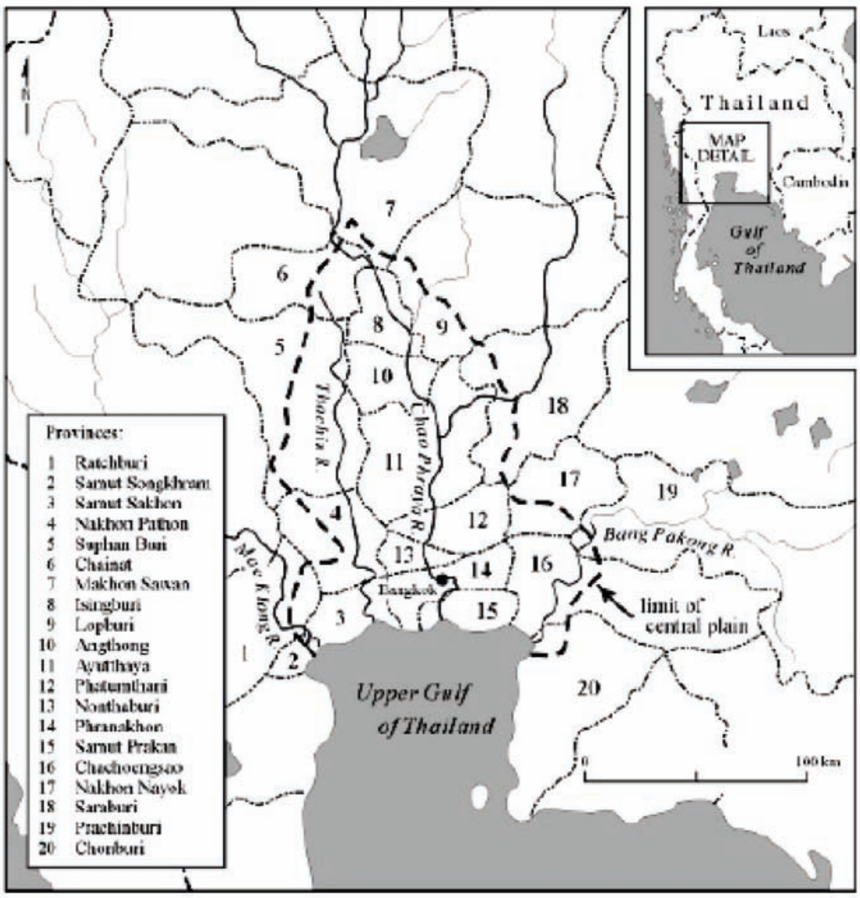
The Central Plain region in Thailand is a vast plain consisting of mainly the Chao Phraya River basin fed by a large network of canals and rivers. It is a lush, fertile valley supporting vast fields of rice, sugar cane, pineapples and other fruits. It is the richest and most extensive rice-producing area in the country and is known as the 'Rice Bowl of Asia' (Figure 6.5.2). Low-salinity shrimp farming in the Central Plain region of Thailand started in early 1980s when the mobility of shrimp farming operations became increasingly constrained owing to:

a) the lack of suitable sites remaining along the coast;
b) the increasing control on the use of mangrove forests by Thai government agencies; and
c) the sharp increase in land values due to competition with other coastal users (Flaherty *et al.* 1999; Flaherty *et al.* 2000).

To cope with the problem of limited availability of coastal areas for shrimp farming in saline water, innovative farmers, supported by relevant government agencies, developed low-salinity shrimp farming techniques in early 1990s. The first low-salinity shrimp farms, evolved through a process of experimentation by small-scale farmers and hatchery operators, appeared along the estuaries of the main rivers draining into the upper Gulf of Thailand. Subsequently, inland low-salinity shrimp farming expanded rapidly after the farming techniques were proven to be technically feasible and economically viable (Szuster 2003a). Successful inland low-salinity shrimp farms can produce around 4-5 tonnes/ha of shrimps twice a year yielding a profit up to 16 times that from farming rice in the Central Plain of Thailand. Because of this high return compared to rice cultivation, rice farmers who can raise the investment capital are usually willing to opt for shrimp farming. Rice farmers who are unwilling or unable to invest may lease their

*Figure 6.5.1 : Black tiger shrimp (*Penaeus monodon*).* *(source: Thongsawad 2005)*

Figure 6.5.2 : Location of the Central Plain of Thailand.
(Source: Szuster & Flaherty 2000)



paddy land areas to outside investors since the rents, in general, greatly exceed what they can get by growing rice (Szuster 2003b).

The largest concentration of inland low-salinity shrimp farms is in the provinces of the lower Central Plain including the Chao Phraya River Delta where rice irrigation infrastructure has been extensively developed (Figure 6.5.3). With ready access to fresh water supplies because of the well-developed irrigation system and the potentially very high profits of shrimp production relative to rice production, a large number of farmers in this area turned their irrigated paddy fields into shrimp ponds (Flaherty *et al.* 2000). An inventory conducted by the Department of Land Development in the late 1990s identified 22,375 hectares of agricultural land devoted to inland low-salinity shrimp farming in the provinces within the Central Plain region (Table 6.5.I). Inland shrimp farming has been found to be most popular in the provinces of Chachoengsao, Prachinburi, Nakhon Pathon, Nakhon Nayok, Chonburi, Suphanburi and Samut Prakan where the pace of inland shrimp farm expansion is beginning to mirror the explosive growth of shrimp culture that occurred along the coast about two decades ago.

The practices for inland low-salinity shrimp farming are generally similar to those for farming the shrimps in coastal mangrove areas. Shrimps are grown in high stocking densities with aerated pond water and commercially-available pelleted feeds and chemo-therapeutants are used. The main difference is the salinity level maintained in ponds during the grow-out period. Coastal shrimp farms maintain pond salinity between 15-30 ppt throughout the grow-out period while the inland farms begin the grow-out phase at pond salinity between 4-10 ppt and use fresh water to offset evaporation and seepage losses, which can reduce pond salinity to near zero by the time of harvest. In order to increase the salinity in the freshwater pond to 3-5 ppt for shrimp farming, about three truckloads (total = 45 tonnes) of salt water at 60 ppt are required for each hectare of the pond area to produce one crop of the shrimp. This results in a salt loading of roughly 2.7 tonnes per hectare per crop of shrimp production. This salt loading figure has been derived by the calculation that there is 60 g of salt in one litre of 60 ppt salt water and for one tonne of 60 ppt saltwater, the salt content would be 60 kg. For 45 tonnes of 60 ppt saltwater the salt content should be around 2,700 kg (60 kg x 45) or 2.7 tonnes, thus the salt loading of 2.7 tonnes. Since almost all inland shrimp farms in the Central Plain region produce two crops per year, annual salt inputs are ~5.4 tonnes per hectare per year (Szuster 2003b; Thongsawad 2005). This figure is substantially higher if the shrimp farms maintain pond salinity level at 10 ppt throughout the grow-out period, and so 5.4 tonnes per hectare annual salt loading figure should be considered conservative.

6.5.1.1 The issue of concern

Rice is the major crop production in the Central Plain of Thailand. Rice is not only the mainstay of the Thai diet, but also has been Thailand's largest single foreign exchange earner for over a century. Rice exports provided the foundation for Thailand's economic development and have been the vanguard for the country's integration into the global economy. The Central Plain is the richest and most extensive rice-growing area in Thailand.

Inland low-salinity shrimp farming could result in large-scale areas of soil becoming saline and unsuitable for rice production. The effects of salinity on the production of rice are well established. Almost all rice varieties are sensitive to salinity as it reduces the growth of seedlings and seed yield of the rice plants, even at low external salt (NaCl) concentrations. Likewise, concern over the salinisation of paddy lands adjacent to shrimp farms has existed in Thailand, particularly in the Central Plain region, for some time. In these areas, rice paddy fields are typically located behind the dense band of shrimp ponds. Complaints were frequently received from local people about low rice yields and the contamination of groundwater aquifers rendering large areas of land unsuitable for rice cultivation due to salinisation.

The conversion of rice paddy fields to shrimp ponds can be viewed as another example of the restructuring and intensification of agriculture, as farmers switch to higher-value crops. For the people living in rural communities, the potential impacts of low-salinity shrimp farming can be seen from two perspectives. On the one hand, shrimp farming holds the promise of improved welfare through direct participation or employment. On the other hand, the farming practice also raises serious concerns over the potential for environmental degradation, resulting in increased marginalisation, exclusion, and reduced economic welfare for local populations. The development of shrimp farms often occurs in areas where incomes from rice farming are low, indebtedness is high, and limited off-farm employment opportunities exist. Rice farmers are therefore under high pressure to choose short-term exploitation and a high profit potential that benefits relatively few people, in preference to long-term resource stewardship. More agricultural land areas are likely to be converted into shrimp farms.

6.5.2 Hazard identification

The rapid expansion of inland low-salinity shrimp farming within rice growing areas of the Central Plain in Thailand has raised concerns regarding the potential adverse environmental changes as well as the suitability of this farming activity within highly productive freshwater agricultural areas. Specific environmental changes include soil salinisation due to leaching of salt from the shrimp pond; water quality degradation as a result of effluent disposal; water pollution; and competition for freshwater resources between the agricultural and aquacultural farmers (Flaherty *et al.* 2000; Pongnak 1999; Jenkins *et al.* 1999). Among these adverse environmental changes, soil salinisation resulting from low-salinity shrimp farming, is the most critical issue due to its potential to cause long-term damage to agricultural areas (Ministry of Science and Technology 1999).

Soil salinisation has negative effects on rice crop productivity, and all rice varieties are sensitive to varying degrees. Salinity can inhibit the growth of rice seed-

Figure 6.5.3 : Low-salinity shrimp farms in Chao Phraya River Delta of the Central Plain Region, Thailand in 2001. (Source : Szuster 2003a)

Table 6.5.I : Area of Low-salinity Shrimp Farms in the Central Plain Region of Thailand in late 1990s. (Source: DLD 1999a)

Province	Area (ha)
Chachoengsao	8375
Prachinburi	4577
Nakhon Pathon	2204
Nakhon Nayok	1752
Chonburi	1631
Suphanburi	1359
Samut Prakan	518
Ayutthaya	451
Ratchaburi	350
Phetchaburi	322
Pathum Thani	244
Samut Sakhon	206
Ang Thong	193
Lopburi	48
Chai Nat	46
Nakhon Sawan	44
Nonthaburi	22
Saraburi	16
Isingburi	12
Samut Songkhram	5
Total	**22,375**

lings, reduce yields, and increase vulnerability to insect pests (Salim *et al.* 1990). Studies conducted by the Thai Department of Land Development (DLD 1999) and the Thai Ministry of Science and Technology (Ministry of Science, Technology and Environment 1999) indicated that seepage of effluents discharged from an inland shrimp farm may increase salinity of soil up to 50 meters or more from the edge of shrimp ponds. Soil salinisation can be a difficult and expensive environmental change to reverse.

Anthropogenic salinisation process has been found to affect 180,000-290,00 ha of agricultural land and it has become a major constraint on agricultural production. Not surprisingly, it puts the objectives of the National Action Plan for Food Security in Thailand (Im-Erb and Anecksamphant 2002; Thailand Development Support Committee 1990) at risk. The following, therefore, provide analyses of risks associated with soil salinisation due to the practice of low-salinity shrimp farming in inland areas of the Central Plain region of Thailand.

6.5.3 Risk assessment

6.5.3.1 Release Assessment

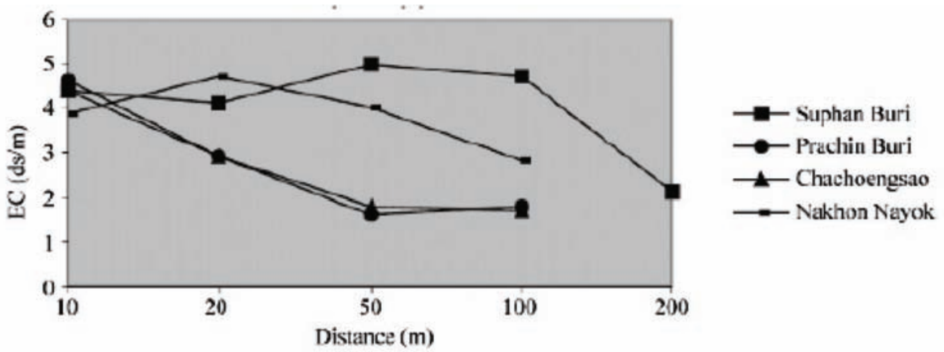
Soil salinisation due to low-salinity shrimp farming can occur directly through the deposition and accumulation of salts in soils located immediately beneath the pond enclosure, or indirectly as a result of seepage into adjacent agricultural areas. The salinisation process is generated by :

a) discharge of wastewater from the shrimp ponds into canals,
b) saltwater leakage or overflow from the shrimp ponds, and
c) leakage from sludge piles in the shrimp farm during rainfalls (Thongsawad 2005).

Indirect soil salinisation can occur through the disposal of saline effluents from shrimp ponds into streams or irrigation canals, which are subsequently used to irrigate rice paddies or orchards. In an earlier study conducted by Braaten and Flaherty (2001), soil salinisation was assessed by analysing the salt balance for an inland shrimp farm in Chachoengsao Province of the Central Plain during May-July 1999. Field data on water fluxes and pond salinities collected from nine ponds in this shrimp farm over one shrimp grow-out cycle were used to model the salt balance. Results indicated that during the grow-out period of shrimp production, seepage represented 38% of the total volume of pond water, which was equivalent to 11.5 tonnes of salt loss per ha per shrimp crop; the pond discharge was at 33% total pond water volume or at 9.7 tonnes salt loss; and the accumulation in pond sediment accounted for 6% total pond water volume or 1.8 tonnes salt loss. The majority of the salt (84% on average) from the shrimp ponds was discharged to the irrigation canals. Much of the salt in the pond sediment was leached to the canal system through flushing of the ponds after the shrimp harvest. Pond discharge caused increases in salinity in the receiving canal water above levels that would impact on yields of irrigated rice and orchard crops. It has also been found that elevated salinity in soil and water in adjacent rice fields was probably related to lateral seepage from the shrimp ponds. Even with shrimp ponds operated at a zero effluent discharge, almost half (~45%) of the initial pond salt content was exported to neighbouring rice fields through seepage, with another 6% of the pond salt content deposited in the pond sediments. It has been found that for an average-sized inland shrimp farm (3-5 ha), the total amount of salt lost to the surrounding environment through seepage, pond water discharge and pond sediments was estimated to be around 23 tonnes per crop of shrimp production; amount of salt loss by lateral seepage through pond walls accounted to 11.5 tonnes per shrimp crop; and the direct discharge of saline water to irrigation canals, the most significant salt transfer pathway, was estimated to be around 9.7 tonnes per shrimp crop (Braaten and Flaherty 2001).

In other studies, criteria for defining the salt-affected area are based on the EC (electromagnetic conductivity) value of 2 dSm^{-1}, for example, any land area that recorded an EC value more than 2 dSm^{-1} is considered to be a salt-affected area and is not suitable for crop production (Im-Erb and Anecksamphant, 2002; Tanavud *et al.* 2000). Twenty shrimp ponds were selected for each of the four provinces in Central Plain for the study; the chosen shrimp ponds had already practiced the shrimp farming for at least three years. The electromagnetic terrain conductivity (EM-38) method was employed to determine EC values in both horizontal and vertical directions and measurement was made at the distances of 0, 10, 20, 30, 40, 50, 100 and 200 m from the shrimps ponds in five provinces in the Central Plain region (Im-

Figure 6.5.4 : EC values of ground water in shrimp ponds in Suphan Buri, Prachin Buri, Chachoengsao and Nakhon Nayok provinces at the distances of 10 - 200 m away from the shrimp pond. *(Source : Im-Erb and Anecksamphant 2002)*



Erb and Anecksamphant 2002). Results of the study showed that the level of soil salinisation, as indicated by the EC values, decreased substantially with the distances away from the shrimp pond. For instance, in Suphan Buri Province, the ranges of the EC values of soil were 2.5-4.2, 2.7-4.3, 2.3 -4.2, 1.9-4.2, 1.7-4.6, 1.5-3.9 and 1.7-3.0 dSm^{-1} for distances of 0, 10, 20, 30, 40, 50, 100 and 200 m away from the shrimp pond, respectively; similar trends of decreasing EC values with distance from the shrimp pond were found in other provinces such as Prachin Buri, Chacheongsao and Nakhon Nayok (Figure 4). Tanavud *et al.* (2000) studied the effect of soil salinisation on the productivity of soil for crop production due to low-salinity shrimp farming in Songkla Lake Basin of southern Thailand. Results of their study indicated that inland low-salinity shrimp farming did cause soil salinisation as far as 100m away from any shrimp pond, with EC values varying from 4.42 dSm^{-1} to 5.24 dSm^{-1}.

6.5.3.2 Exposure Assessment

The expansion of shrimp farming in the freshwater area of the Central Plain and its potential impact on rice cultivation has been a serious concern in Thailand since the first boom of pond shrimp farming occurred during the late 1980s (Thailand Development Support Committee 1990). Results of earlier studies indicated that the total area of salt-affected soils in Thailand, by both natural phenomena and anthropogenic processes, amounted to 3.4 million ha of which the Central Plain region accounted for 0.18 million ha, and in that area salinisation was mainly induced by shrimp farming (Szuster 2003b; FAO 2006).

As mentioned earlier, Im-Erb and Anecksamphant (2002), in their studies on low-salinity shrimp farming and soil salinisation, indicated that soils were highly saline with EC values exceeding 2 dSm^{-1} even in the area within 50m away from the inland low-salinity shrimp ponds in the Central Plain region. Studies on the effects of soil salinisation have suggested that saline soils with EC values greater than 2 dSm^{-1} occured to all agricultural land converted to shrimp ponds (Committee on Inland Shrimp Farming 1998; Im-Erb and Anecksamphant 2002). It has been estimated that the total area of soil affected with salt in five provinces (Suphan Buri, Prachin Buri, Nokhon Si Thammarat, Nakhon Nayok and Chacheongsao) of the Central Plain was approximately 90,650 ha including the areas of the shrimp farms. The total area of soil affected by the salinisation process in the whole Central Plain region is likely to be 2-3 times the 90,650 ha (for example, 190,000-280,000 ha) when shrimp farming areas in the other 15 provinces of the Central Plain (Im-Erb and Anecksamphant 2002) are included in the estimate.

Most of the lands in the Central Plain region are highly productive for rice farming (Szuster 2001) and their soil quality has been negatively affected by conversion into shrimp farms. The issue of soil salinisation within the freshwater areas of the Central Plain region is highly controversial because many low-salinity shrimp farms have been sited within highly productive rice growing areas.

6.5.3.3 Consequence Assessment

Soil salinisation has negative effects on rice crop productivity since all rice varieties are sensitive to varying degrees of salinity which can inhibit the growth of rice seedlings, reduce yields, and increase vulnerability to insect pests (Salim *et al.* 1990). Accumulation of salts in soil can occur to the extent that results in degradation of vegetation and soil quality. Salinity can affect all stages of crop growth by:

a) changing the osmotic potential of soil water and toxicity of specific ions;
b) increasing ion concentrations within the plant, interfering with plant growth; and
c) affecting soil aeration and cation exchange (Greenland 1997).

As a result of these changes, the following effects on the growth of the plants can be observed:

(i) morphological and anatomical changes in leaf anatomy and succulence;
(ii) changes in microscopic and sub-microscopic structure of leaf, stem and root growth; and,
(iii) physiological, metabolic and biochemical changes in enzyme activities.

In saline conditions, the solute concentration of soil water increases, which in turn reduces or reverses the soil to root osmotic gradient which may lead to difficulty in extraction of water by the plants where water molecules tend to move to the areas of lower free energy. These changes can reduce growth or cause death of the plants growing in saline soil (Yadav 2005).

In Thailand, saline soil with EC values exceeding 2 dSm^{-1} can render productive land unsuitable for arable crop production. By comparing the characteristics of saline and normal soils, Tanavud *et al.* (2001) found that saline soil with EC value exceeding 2 dSm^{-1} has significantly lower organic carbon and total nitrogen content (key nutrient components indicating fertility of the soil), clay content and water retention capacity. Thus, inland low-salinity shrimp farming results in large-scale soil salinisation, and causes the soil to be unproductive for agricultural crop production (Tanavud *et al.* 2001).

Agricultural yields in coastal areas of Thailand tended to be rather low, due to marginal soil conditions, and this situation was aggravated by saline seepage from shrimp ponds or saltwater intrusion produced by groundwater withdrawals for shrimp culture (Phillips *et al*. 1993). The destruction of sugar palms, originally planted in coastal rice fields which later became salinized due to the practice of low-salinity shrimp farming, is a highly visible reminder of the aquaculture-induced soil salinisation problem (Phonga *et al.* 2000). It is anticipated that further expansion of inland low-salinity shrimp farming in the Central Plain is likely to aggravate soil salinisation and degrade water resources rendering these natural resources unsuitable for rice and other agricultural crop productions (Braaten and Flaherty 2001).

In Thailand agricultural production is the main source of national revenue. Since soil salinisation associated with inland low-salinity shrimp farming is a critical environmental issue that affects rice production, the issue warrants an analysis of the hazard of salinisation due low-salinity shrimp culture. Below, the logic model concept is used to identify the causes and effects of the soil salinisation resulting from the practice of low-salinity shrimp farming in the Central Plain region of Thailand. A series of steps and processes leading to the occurrence of soil salinisation resulting from inland low-salinity shrimp farming are, therefore, summarised in a logic model shown below.

The Logic Model:

Process of Concern (Hazard): Low-salinity shrimp farming in agricultural land in the Central Plain of Thailand

End Point of Concern: 180 000-290 000 ha of soil in agricultural land in the Central Plain of Thailand are made unsuitable for rice production with an EC greater than 2dSm^{-1}.

Logic Model Steps:

1. Development of low-salinity shrimp farms in agricultural land of Central Plain in Thailand.
2. Practices of the low-salinity shrimp farming will introduce significant quantities of salt.
3. There will be an increase of soil salinity due to low-salinity shrimp farming.
4. Large areas of soil in agricultural lands will be affected.
5. Productivity of soil in agricultural land of the Central Plain decreased.
6. At least 180,000-290,000 ha of soil in agricultural land in Central Plain of Thailand are made unsuitable for rice production.

The causal relation of the logic model steps is presented in Figure 6.5.5.

1. Development of low-salinity shrimp farms in agricultural land of Central Plain in Thailand.

   Inland low-salinity shrimp farming has developed in the Central Plain region mainly due to the lack of suitable sites remaining along the coast and the sharp increase in land values due to competition with other coastal users. The farming practice developed rapidly and production in mid-1990s represented as much as 30-40% of Thailand's total production of farmed shrimps. The farming area accounted for around 22,375 hectares of agricultural land in the provinces within the Central Plain region. The pace of expansion of inland shrimp farms mirrors the explosive growth of shrimp culture that occurred along the coast in Thailand about two decades ago. The farming techniques are well-developed and produce higher profits than rice cultivation, so, without further government intervention, this type of cultivation will expand.

   Probability of the risk of the further large scale development of low-salinity shrimp farms is considered to be relatively high, due to the pressure of factors including: (a) in Thailand, shrimp farming plays an important role in its national economy; (b) government authorities have been supportive of shrimp farming, encouraging farmers to raise more shrimps for export (c) the area used for such shrimp culture is large; and (d), should it be considered, removal of the industry would require a protracted period to allow for adjustment in the communities that have come to rely on the income from shrimp farming. The Severity of change is therefore High, the probability that this outcome will be realised is High and the uncertainty is Low.

2. Practices of low-salinity shrimp farming will introduce significant quantities of salt.

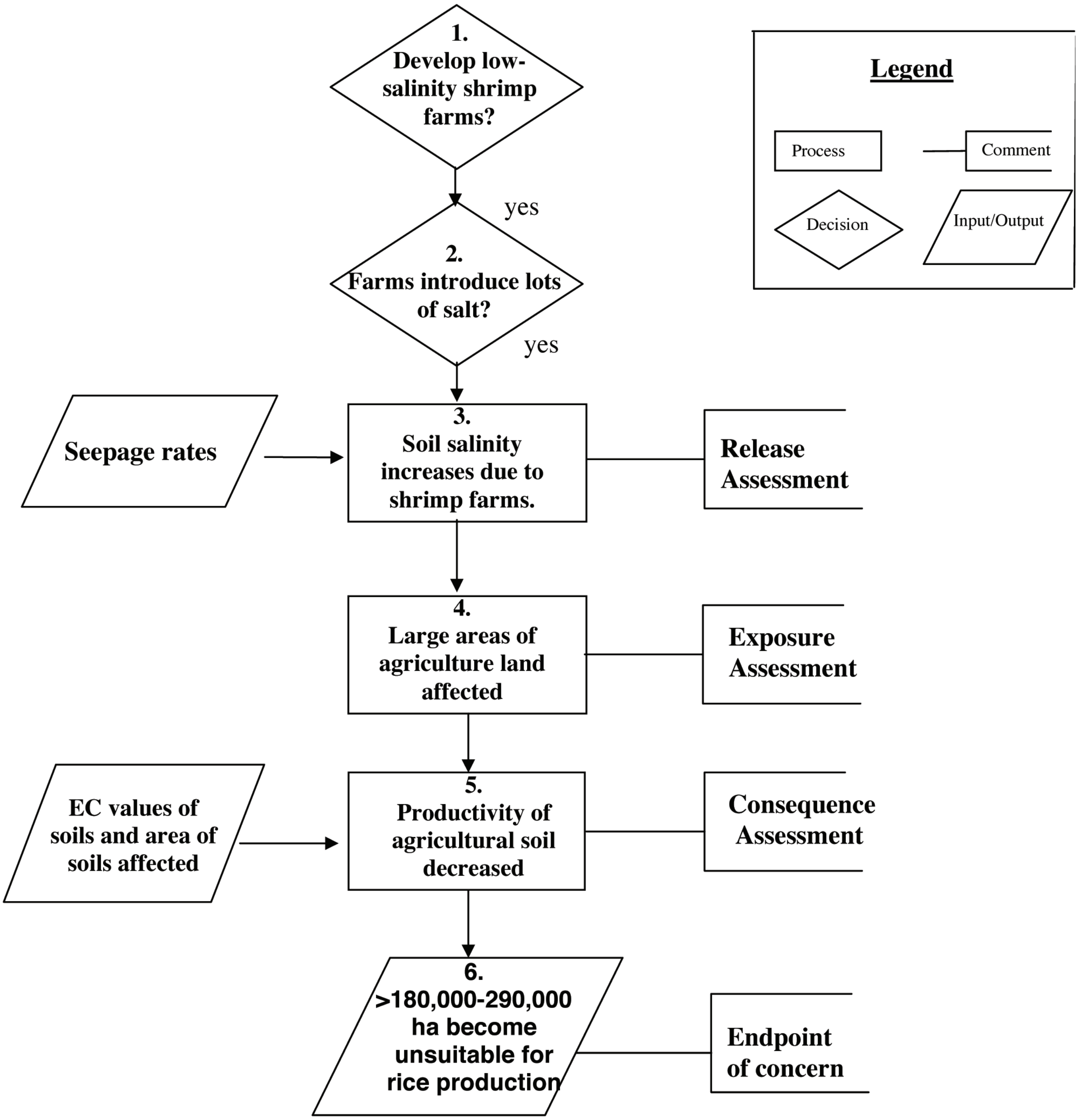
   In the conventional coastal shrimp farming, the salinity of the pond water varies according to the salinity of the incoming water, usually in the range of 15-30 ppt. For inland shrimp farming, more complex management of pond water salinity is practiced. To maintain a low salinity of 3-5 ppt in each shrimp pond (1.0 ha), three truckloads (15 metric tons each truckload), for example, 45 metric tons of salt water at 60 ppt are required. Since about 30% of the pond water will be replaced with new water of similar salinity level (3-5 ppt) every 10 days, about three truckloads of 60 ppt salt water will be required per water change for the whole farm. The total volume of high salinity water required per month would be 135 metric tons; the volume for the whole grow-out period (four months) would be 540 metric tons. The total volume of high salinity water required for one production cycle for the farm would be 585 metric tons. Salinity in the grow-out ponds 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. Reservoir ponds are used to store low-salinity water for water exchange in the grow-out ponds. The shrimps are harvested after four months of rearing. Two crops of shrimps can be produced each year. These farming techniques have been well-developed and are known to be commercially viable.

   The quantities of salt introduced to the soil by shrimp culture are high relative to other sources of salt. The area over which this occurs is also large. No other commercially proven technology has been developed for raising these shrimp species in low salinty water. Consequently, it is highly likely this type of shrimp culture will continue for the foreseeable future. The Severity of change is therefore High, the probability that this outcome will be realised is High, and the uncertainty is Low.

3. There will be an increase of soil salinity due to low-salinity shrimp farming.

   The process of causing the increase of soil salinity due to low-salinity shrimp farming in the Central Plain of Thailand can be either of

Figure 6.5.5 : Logic model for risk of soil salinisation due to low salinity shrimp farming. Numbers in each box refer to a logic model step used in the assessment.



primary or secondary nature. In the primary salinisation, the natural process of parent material weathering is relatively small compared to the secondary salinisation. In the secondary salinisation, accumulation of salt in the soil is caused by mobilisation of stored salt from the soil profile and/or ground water due to human activities. Soil salinisation due to low-salinity shrimp farming could be categorised under the secondary salinisation process. Past experience has shown that a significant portion of the salt from the shrimp ponds enters the surrounding agriculture lands.

Soil salinisation of the agricultural land in the Central Plain region is highly likely to continue. The area of the farms from which the salt originates is large and, as indicated above, is likely to continue for the foreseeable future. The Severity of change is therefore High, the probability that this outcome will be realised is High and the uncertainty is Low.

4. Large areas of soil in agricultural land will be affected.

   In Thailand, saline soil with EC (electromagnetic conductivity) value exceeding 2 dS/m has been known to render productive land unsuitable for arable crop production. It has been estimated that the total area of soil affected in five provinces (Suphan Buri, Prachin Buri, Nokhon Si Thammarat, Nakhon Nayok and Chacheongsao) of the Central Plain region is approximately 90,650 ha, including the area of the actual shrimp farms. The total area of soil affected by the salinisation process due to low-salinity shrimp farming in the Central Plain region is likely to be 2-3 times of the 90,650 ha (for example, around 190,000 - 280,000 ha) if shrimp farming areas in other 15 provinces of the Central Plain are included. Therefore, the degree to which the rice growing agricultural soils are modified (relative to thresholds for rice culture) is high, the area affected is large and given the pattern of development in these areas, the salinisation of farm land likely to last for a considerable period. The Severity of change is therefore High, the probability that this outcome will be realised is High and the uncertainty is Low.

5. Productivity of soil in agricultural land of the Central Plain decreased.

   Salinisation as a result of the low-salinity shrimp farming has caused serious and severe decline in soil productivity and crop yields. Salinity has been found to reduce efficient use of water (for example, crop yield per unit of water) causing reductions in the return from capital investment and labour inputs. Salt-affected soil is:

- more fragile and subjected to other forms of degradation such as reduction in land green cover and becoming vulnerable to wind and water erosion;

- less responsive to any other input, for example, the soil crop yield response to fertiliser is less, as salinity is a limiting factor; and

- less flexible for alternative land use as farmers are forced to cultivate only salt-tolerant crops which are not always be the high income cash crops.

   It has been found that in the Central Plain region, saline soil with EC value exceeding 2 dS/m has significantly lower organic carbon and total nitrogen contents (they are key nutrient components indicating fertility of the soil), clay content and water retention capacity. The rehabilitation of saline soil also needs high investment, and in economic terms the cost of rehabilitation may reach 65% and 100% of the total crop production value in moderate to severe conditions, respectively. Large areas of soil in the Central Plain region will have highly reduced productivity, so long as the low-salinity shrimp farming continues. The probability in this respect is high with little uncertainty.

6. At least 180,000-290,000 ha of agricultural land of Central Plain in Thailand are made unsuitable for rice production (end-point of concern).

   More agricultural land areas are likely to be converted into shrimp farms, although the individual lease areas to be converted to shrimp production may be small. It has been estimated that the total area of soil already affected by salt (with EC value exceeding 2 dS/m) in five provinces (Suphan Buri, Prachin Buri, Nokhon Si Thammarat, Nakhon Nayok and Chacheongsao) of the Central Plain region is approximately 90,650 ha including the area of shrimp farms proper. The total area of soil affected by the salinisation process due to low-salinity shrimp farming in the Central Plain region is likely to be 2-3 times the 90,650 ha (for example, around 190,000 - 280,000 ha) if shrimp farming areas in other 15 provinces of the Central Plain are included. The Severity of change is thought to be close to the endpoint threshold established before the analysis and is therefore Moderate. The probability that this outcome will be realised is High and the uncertainty is Low.

   The severity, probability and uncertainty of risks associated with the logic steps in the analysis of soil salinisation resulting from the practice of inland low-salinity shrimp farming in the Central Plain of Thailand have been assessed. Results of the assessment are summarised in Table 6.5.II.

Table 6.5.II : Logical model outcomes.

Steps in the logic model	Intensity	Spatial Extent	Duration	Overall Severity	Probability	Uncertainty
Step 1. Development of low-salinity shrimp farms in agricultural land of Central Plain in Thailand.	H	H	H	H	H	L
Step 2. Practices of the low-salinity shrimp farming will introduce significant quantities of salt.	H	H	H	H	H	L
Step 3. There will be an increase of soil salinity due to low-salinity shrimp farming.	H	H	H	H	H	L
Step 4. Large areas of soil in agricultural lands will be affected.	H	H	H	H	H	L
Step 5. Productivity of soil in agricultural land of the Central Plain decreased.	H	H	H	H	H	L
Step 6. At least 180,000-290,000 ha of soil in agricultural land in Central Plain of Thailand are made unsuitable for rice production.	H	M	H	H	H	L
Final Rating [4]				H	H	L

Explanatory notes:

Severity = C – very severe, H – high, M – Moderate, L – Low, N – Negligible The three components of severity - intensity, the geographic extent, and the duration of the change (in grey) - are separately assessed to inform an overall severity rating.

Overall Severity = the highest of the 3 severity sub-components

Probability = H – High, M – moderate, L – Low, EL – Extremely Low, N – Negligible

Uncertainty = H- Highly uncertain, M – Moderately uncertain, L – Low uncertainty

The final rating for the Probability is assigned the value of the element with the lowest level of probability. The final rating for the Severity (intensity of interaction) is assigned the value of the step with the lowest risk rating (e.g., Medium and Low estimates for the logic model steps would result in an overall Low rating). The final value for severity for each specific risk is assigned the value of the lowest individual logic model estimate. The final rating for the Uncertainty is assigned the value of the element with the highest uncertainty level (i.e. the least certainty).

6.5.3.4 Risk Estimation

In order to deal with the problem of soil salinisation in the Central Plain region, the Royal Thai government has banned the expansion of inland shrimp farming in Thailand's irrigated rice growing areas in the late 1998s on the basis of a recommendation from the National Environment Board (Srivalo 1998). Governors in coastal provinces were subsequently instructed to designate land as freshwater area where shrimp farming would be prohibited, or as brackish water area where shrimp farming could continue.

However, in spite of the prohibition on shrimp farming within freshwater provinces over the past decade, concerns continue to exist over the capacity for enforcement of 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 factors such as: (a) in Thailand, shrimp farming plays an important role in its national economy; and (b) government authorities have been supportive of shrimp farming encouraging farmers to raise more shrimps for export. 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, renewed pressure is likely to develop for the expansion of shrimp farming into freshwater areas (Vandergeest *et al.* 1999; Thamrong and Laura 2003).

Concurrently with the ban on inland shrimp farming on designated freshwater area, the Thai Government also introduced plans to reclaim the land affected by shrimp farming to be reused for agricultural purposes (Im-Erb and Anecksamphant 2002). At the same time, the Thai shrimp farming industry lobbied strenuously for a reversal of the ban on shrimp farming in freshwater areas mainly in the Central Plain region. While it appeared for a time that the restriction on shrimp farming in freshwater areas would be relaxed, intense opposition from environmental groups and support from His Majesty King Bhumibol of Thailand may finally convince the National Environment Board to re-affirm its original decision and maintain the ban (Szuster 2003b).

With regard to soil salinisation, the Thai government has imposed aquaculture zoning strategies which are being developed to mitigate the environmental impacts of shrimp faming on agricultural land use. A proposal by Thailand's Land Development Department (1999) would restrict shrimp farms in the Central Plain region to designated brackish-water zones within three coastal provinces (Samut Prakarn, Bangkok, and Samut Sakhon). Farm construction within these provinces would be limited to regions possessing soil parent materials with a conductivity of 2 dSm^{-1} or greater (measured at 1.5 m below the surface). This would restrict shrimp farms to less productive areas with saline sediments located relatively close to the surface (Szuster 2003b). Shrimp farms within approved areas would also be required to install perimeter ditches and / or pond liners to mitigate indirect salinisation effects, and the disposal of saline pond effluent during periods when rice farmers are accessing irrigation water supplies would be controlled (Boyd 2001). Enforcement of these measures has been slow and inconsistent, and it remains to be seen whether all shrimp farms within restricted areas will cease production or switch to alternative crops. However, restricting shrimp farming in fresh water zones still represents a prudent strategy for preserving agricultural land, and the implementation of this strategy in the Central Plain region of Thailand should represent a high priority for the Government of Thailand (Szuster 2003a)

6.5.4 Risk Management and Mitigation

The risk(s) associated with each of the logic steps could be mitigated through a number of modifying practices as well as the research and development (R&D) activities taken by the relevant authorities. Such activities for each of the logic steps were analysed and results of the analysis are summarised in Table 6.5.III.

6.5.5 Summary and Lessons Learned

The practice of commercial low-salinity shrimp farming in the Central Plain region of Thailand was technically and economically viable. As a result, rapid development of low-salinity shrimp farms occured in the inland agricultural lands, which are used for rice production. Although inland low-salinity shrimp farming could reap short-term profitable returns, it is considered to be an environmental hazard that introduces soil salinisation to a large area. The anthropogenic salinisation process has been found to degrade soil resources causing long-term damage to agricultural areas and it has become a major limitation on agricultural production, likely to place at risk the National Action Plan for Food Security in Thailand. Agricultural land, once it is salinised and its soil quality is damaged, may be difficult and expensive to reverse. Soil salinisation resulting from the practice of low-salinity shrimp farming does introduce risks for the agricultural development and affects the agricultural production, particularly rice production, in the Central Plain region, which isthe richest and most extensive rice-producing area in Thailand. The expansion of shrimp farming in freshwater area of the Central Plain and its potential impact on rice cultivation has become a serious concern in Thailand since the first boom of pond shrimp farming occurred during the late 1980s. Soil salinisation, therefore, has negative effects on rice crop productivity since all rice varieties are sensitive to varying degrees of salinity which can inhibit the growth of rice seedlings, reduce yields, and increase vulnerability to insect pests. An estimated 180,000-290,000 ha of soil in agricultural land of the Central Plain in Thailand could become unsuitable for rice production due to the practice of the inland low-salinity shrimp farming. A risk analysis to elucidate the causal relationship of these processes of environmental interactions was attempted.

The protocol of risk analysis adopted herewith was based on the initial framework of the environmental risk analysis for mariculture developed by the ICES WGEIM. The protocol essentially involves first the elaborated description/explanation of 'Hazard identification' and the three components of the risk assessment - release assessment, exposure assessment and consequence

Table 6.5.III : A summary of risk mitigation and research options.

Steps in the logic model	Probability	Mitigation	Uncertainty	R&D
Step 1. Development of low-salinity shrimp farms in agricultural land of Central Plain in Thailand.	H	Implement ban on further development of low-salinity farming in Freshwater arable land	L	R&D on alternative freshwater technologies for shrimp production or alternative freshwater species for culture
Step 2. Practices of the low-salinity shrimp farming will introduce significant quantities of salt.	H	Permit only fully freshwater cultivation technologies	L	Implement new wholly freshwater technologies for shrimp production and/or new freshwater species for profitable culture
Step 3. There will be an increase of soil salinity due to low-salinity shrimp farming.	H	Permit the use of only zero discharge technologies. Avoid building saltwater reservoir in area where it might enter groundwater.	L	
Step 4. Large areas of soil in agricultural lands will be affected.	H	Permit the use of only zero discharge technologies.	L	
Step 5. Productivity of soil in agricultural land of the Central Plain decreased.	H	Implement zoning that restricts shrimp farming to designated areas. Create impermeable drainage conduits and/or lined dams that allow water reuse. For inland areas encourage use of salt tolerant plant species such as Acadia ampliceps or Azadirachta indica to lower groundwater levels. In coastal areas use dikes to prevent saline water intrusions.	L	R&D to identify the soil process in order to enhance the ability to manage the problem and to develop remedial measures for improving the saline soils.
Step 6. At least 180 000-290 000 ha of soil in agricultural land in Central Plain of Thailand are made unsuitable for rice production.	H		L	

assessment. The analysis is further strengthened by the development of a logic model which may represent the analysis of one hazard and is consisted of several simple steps. The logic model steps may represent a summary of the earlier elaborated description on the risk assessment for a particular hazard but contains clear pathways on how risks produced from the hazard may exert the impacts on the environment - including human and physical environment. The logic model also provides the basis for deriving the risk evaluation, risk management and risk communication. In the present case study, the concept of the above risk analysis protocol was successfully applied to analyze the environmental risks due to the occurrence of the environmental hazard ¨ the practice of low-salinity shrimp farming in agricultural land of the Central Plain of Thailand ¨ and how these risks could be evaluated and mitigated.

6.5.6 Literature cited

Avault, J.W. (1993): Aquaculture: environmental and conservation considerations. Research Report, 19(1), 64-67.

Boromthanarat, S. and Nissapa, A., (2000): Shrimp farming experiences in Thailand: a continued pathway for sustainable coastal aquaculture. Submitted to Network of Aquaculture Centre in Asia-Pacific, Bangkok, 113 p.

Boyd, C. (2001): Inland shrimp farming and the environment. World Aquaculture, 32(1), 10-12.

Boyd, C. and Musig,Y. (1992): Shrimp pond effluents: observations of the nature of the problem on commercial farms. In: Wyban,J. (ed.). Proceedings of the Special Session on Shrimp Farming. World Aquaculture Society, Baton Rouge, LA.

Braaten, R. O. and Flaherty, M. (2001): Salt balances of inland shrimp ponds in Thailand: implications for land and water salinization. Environmental Conservation, 28(4), 357-367.

Committee on Inland Shrimp Farming (1998): Environmental impact of shrimp farming in freshwater area. Ministry of Science, Technology and Environment. Bangkok, Thailand.

Department of Land Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand. Retrieved from: http://www.tucson.ars.ag.gov/isco/isco12/VolumeII/SoilDegradationDuetoShrimpfarming.pdf

DLD (1999): Rehabilitating land affected by shrimp farming in freshwater Areas. Department of Land Development (DLD), Ministry of Science, Technology and Environment, Bangkok, Thailand.

DOF (2004): Thailand total main shrimp production during 1985-2004. Department of Fisheries (DOF), Bangkok, Thailand. http://www.fisheries.go.th/it%2Dstat/

FAO (2006): Extent and causes of salt-affected soils in participating countries - Thailand. Food and Agriculture Organization (FAO) of the United Nations.
http://www.fao.org/ag/agl/agll/spush/topic2.htm#thailand

Flaherty, M., Vandergeest, P. and Miller, P. (1999): Rice paddy or shrimp pond: tough decisions in rural Thailand. World Development, 27(12), 2045-2060.

Flaherty, M., Szuster, B.W. and Miller, P. (2000): Low salinity shrimp farming in Thailand. Ambio 29 (3), 174-179.

Greenland, D.J. (1997): The Sustainability of Rice Farming. CAB International, New York, 320 p.

Im-Erb, R. and Anecksamphant, C. (2002): Soil degradation due to shrimp farming and preventive measures. Paper presented in 12th ISCO Conference in Beijing, 2002.

Jenkins, S., Smith, T., Tookwinas, S., and Phillips, M.J. (1999): An assessment of the status of shrimp farming in Thailand: key issue for research. Canberra: Australian Centre for International Agricultural Research: 14-68.

Lindberg, T. and Nylander, A. (2001): Strategic environmental assessment on shrimp farms in the southeast of Thailand. Uppsala: The Swedish University of Agricultural Science, Minor Field Studies No. 176.

Miller, P., Flaherty, M. and Szuzter, B. (1999): Inland shrimp farming in Thailand. Aquaculture Asia, 4(1), 27-32.

Ministry of Science, Technology and Environment (1999): Environmental impact of shrimp farming in freshwater areas. Committee on Inland Shrimp Farming, Bangkok, Thailand.

Phillips, M.J., Lin, C.K. and Beveridge, M. (1993): Shrimp culture and the environment: Lessons from the world's most rapidly expanding warmwater aquaculture sector. In: R. Pullin, H. Rosenthal and J. Maclean (eds.). Environment and Aquaculture in Developing Countries, Manila: International Center for Living Aquatic Resources Management (ICLARM), pp. 171-197.

Phonga, N.D., Mya, T. V., Nanga, N.D., Tuong, T.P., Phuocc, T. N. and Trungc, N.H. (2000): Salinity dynamics and its implication on cropping patterns and rice performance in shrimp rice systems in My Xuyen and Gia Rai. Paper submitted to the ACIAR-funded workshop “An evaluation of sustainability of farming systems in brackish areas of the Mekong Delta, Vietnam.” Can Tho University, Vietnam, 12 – 15 December 2000.

Pongnak, W. (1999): Case study on the impact and conflict in using the nation’s freshwater land resources for farming panaeid shrimp. Greenline, No. 4 (June-September 1999, 6-15.

Salim, M., Saxena, R. and Akbar, M. (1990): Salinity stress and varietal resistance in rice: Effects on whitebacked planthopper. Crop Science 30 (6), 654-659.

Smith, P.T. (ed.), 1999. Coastal shrimp aquaculture in Thailand: Key issue for research. ACIAR Technical Report No.47, ACIAR, Bangkok, Thailand, 131 p.

Srivalo, P. (1998): Cabinet bans inland shrimp farms. The Nation, 8 July 1998.

Szuster, B.W. (2001): Cumulative environmental effects of low salinity shrimp farming in Thailand. Unpublished Ph.D. Dissertation, Department of Geography, University of Victoria, Australia.

Szuster, B. W. (2003a): Shrimp farming in Thailand’s Chao Phraya River Delta. International Water Management Institute (IWMI), Stockholm, Sweden, 48 p.

Szuster, B. (2003b): Shrimp farming in Thailand’s Chao Phraya River Delta: boom, bust and echo. International Water Management Institute (IWMI), Stockholm, Sweden, 53 p.

Szuster, B.W. and Flaherty, M.S. (2000): Inland low-salinity shrimp farming in the Central Plains region of Thailand. In: Proceedings of the International Conference ‘The Chao Phraya Delta: Historical Development, Dynamics and Challenges of Thailand’s Rice Bowl’, December 2000, Vol. 1. Kasetsart University, Bangkok, pp.159 - 170. http://std.cpc.ku.ac.th/delta/conf/prog_list.htm

Tanavud, C., Yongchalermchai, C., Bennu, A. and Densrisereekul, O. (2000): The expansion of inland shrimp farming and its environmental impacts in Songkla Lake basin. Kasetsart Journal (Natural Science), 35, 326-343.

Thailand Development Support Committee (1990): Invasion of the prawn farms. Thai Land Development Newsletter 18: 32-36.

Thamrong, M. and Laura, M. J. (2003): Rice versus shrimp production in Thailand: is there really a conflict? Journal of Agricultural and Applied Economics, April 2003. http://www.findartcles.com/article/mi_qa405/is_200304/ai_n9192946/

Thongsawad, S. (2005): Prevalence survey of non-virus in Pacific white shrimp (*Litopenaeus vannamei*) in Thailand. M. Sc., Thesis, Chiang Mai University, Thailand and Ferie Universitat, Berlin, Germany, 65 p.

Vandergeest, P., Flaherty, M. and Miller, P. (1999): A political ecology of shrimp aquaculture in Thailand. Rural Sociology 64 (4), 573-596.

Yadav, R. D. (2005): Modeling salinity affects in relation to soil fertility and crop yields: a case study of Nakhon Ratchasima, Nong Suang District, Thailand. M. Sc., Thesis, International Institute for Geo-information Science and Earth Observation, Thailand, 150 p.