Kasetsart J. (Nat. Sci.) 35 : 326 - 343 (2001)

The Expansion of Inland Shrimp Farming and Its Environmental Impacts in Songkla Lake Basin

Charlchai Tanavud[1], Chao Yongchalermchai[1], Abdollah Bennui[2] and Omthip Densrisereekul[1]

ABSTRACT

Amidst the heightened awareness of environmental issues in the Songkla Lake Basin, widespread concern has also emerged over potential environmental impacts of inland shrimp farming. Outbreaks of disease in the coastal areas and the development of low salinity culture techniques have been major factors behind the migration of shrimp farming into the basin's freshwater areas well inland from the coast. Over a period of 18 years, from 1982 to 2000, shrimp cultivation areas rose dramatically from 3,491 ha to 7,799 ha, equivalent to an increase of 123.4 %. Further analysis has revealed that 3,347 ha, or 77.7 % of the increase in culture areas came from rice fields. The graphic consequence has been well-demonstrated problems of soil and water degradation resulting from the culture operations. Farmed soils possessed several chemical and physical limitations to the establishment of vegetation. The major chemical factors were largely associated with high salinity level and low organic carbon content whereas high bulk density and low saturated hydraulic conductivity were the major physical limitations. Analysis also revealed that salinity levels in soils located within 0, 20, 40, 60 and 100 meters distance from the culture pond were high and well above the suggested critical value of 1.6 mS/cm, indicating that soluble salt could be a limitation to the establishment of plants on these soils. Besides the salinization of soils, the discharge of untreated pond effluents caused deterioration of the quality of waterbodies in close proximity to the pond through the elevation of salinity level, BOD concentration and suspended solid level. The degradation of soil and water quality that occurs could render large areas of productive land unsuitable for arable crop husbandry. Moreover, poor water quality could contribute to outbreaks of disease which, in turn, resulting in a catastrophic collapse of the industry. Management strategy for the reversal of such degradation is discussed.

Key words : shrimp farming, environmental impacts, land use zoning plan, Songkla Lake Basin.

INTRODUCTION

Songkhla Lake Basin covers an area of approximately 8,463 km^2, of which 1,043 km^2 is the lake surface, and stretches southwards for over 150 kilometers along the eastern coast of the Southern Thai Peninsula. The basin consists of three main topographic units: a range of mountains to the west and south of the basin, foothills and terraces, and broad plains on the east and west sides

1 Faculty of Natural Resources, Prince of Songkla University, Hat Yai, Songhla 90112, Thailand.
2 Research and Development Office, Prince of Songkla University, Hat Yai, Songhla 90112. Thailand.

of the lake. The lake, which is divided into three distinct but interconnected waterbodies viz. Thale Noi, Thale Luang and Thale Sap Songkla (NEDECO, 1972), is a shallow coastal lagoon formed by interaction of land and ocean processes over geological time (NESDB and NEB, 1985). The lakes connecting to the Gulf of Thailand through a narrow channel outlet are subject to seasonal fluctuations in salinity (Lesaca, 1977). During the dry season, salinity levels in the lake water increase due to intrusion of seawater from the Gulf of Thailand. Salinity level in Thale Sap Songkla may rise to 25 ppt, 15-20 ppt in Thale Luang and almost zero in Thale Noi (DANCED and MOSTE, 1999).

The basin experiences an annual rainfall of approximately 2,000 mm, with a distinct wet season from October to January (DANCED and MOSTE, 1998). More than 100 streams of all sizes drain the basin from the western mountain range into the lakes (Lesaca, 1977). Total annual inflow from streams to the entire lake system is 5,200 million m^3 (Thimakorn and Vongvisessomjai, 1979). Storage in the lakes is 1,681 million m^3 to mean sea level. Only 0.6 % of the basin's total land areas is regarded as having severe erosion, while 4.0 % has moderate erosion and 95.4 % has slight erosion (Tanavud *et al*., 2000). Sediment rate in the lake has been estimated at 1.0 mm yr^{-1} (Tanavud *et al*., 2000).

The economy of the basin is agricultural in nature. Rice is cultivated in the lowlands, while rubber and mixed orchard are cultivated in the terrace and foothills (Tanavud *et al*., 1999). The mountain ranges are covered with evergreen forest. Over recent years several parts of the range have been dedicated as wildlife sanctuaries or national parks. Animal husbandry and fisheries also contribute to the local economy. The Songkhla Lake Basin, which was once the richest and most extensive rice growing area, was formerly described as the rice bowl of southern Thailand (NESDB and NEB, 1985).

It was not until the early 1980s that shrimp cultures for black tiger shrimp (*Penaeus monodon)* were introduced by the government as a means of providing nutrition, improving household incomes and enhancing employment opportunities for the basin's population (Phillips and Barg, 1999). Although it is undeniable that the growth of shrimp culture industry has benefited the social and economic well-being of the people in rural areas, there has also been environmental disruption generating impacts detrimental to the welfare of the rural people (Chin and Ong, 1997). While the establishment of shrimp farming in the basin's freshwater areas is broadly known, there have been no detailed assessments of the nature and actual extent of shrimp cultivation areas, and the environmental impacts generated by the culture industry.

It is in this context that the present study was undertaken. The objectives of the study are (i) to ascertain the nature and areal extent of shrimp cultivation areas in Songkla Lake Basin, and (ii) to evaluate the impacts of shrimp farming on soil and water environments in the areas of operation.

MATERIALS AND METHODS

Areal extent of shrimp farming

To determine the areal extent of shrimp farming in Songkla Lake Basin, Geographic Information Systems (GIS) was used to compile spatially explicit data layers that describe the basin's land use. All spatial analysis operations were performed using PC ArcInfo 3.5.2 and Arcview 3.2 software (ESRI, 1998). To allow for comparisons, land use was determined for two time periods; 1982 and 2000. The data layers selected as input data for PC ArcInfo operations included basin boundary maps and land use maps. In ArcInfo GIS, maps can be converted into a digital format by tracing them with a digitizer. In the present study, basin boundaries were created in ArcInfo GIS by digitizing from the 1:50,000 topographic map produced by the Royal Thai Survey Department. The 1982 land use coverage was generated in ArcInfo GIS by digitizing from a paper map displaying 1982 land use at a scale of 1:50,000 prepared by the Department of Land Development. The 2000 land use coverage was digitized from a paper map visually interpreted from the 1:50,000 Landsat TM images for Songkla Lake Basin acquired in 2000. Ground truthing was also conducted to assist in the imagery classification and validate the final results. Following the preparation of land use coverages for the two dates, the areas of each type of land use for each period were calculated using the TABLES and CALCULATE commands in PC ArcInfo. Changes in land use between the two inventories were determined by overlaying land use coverages between the two dates using PC OVERLAY's UNION and INTERSECT commands. The acreage of land areas within 50 m and 100 m from the edge of the shrimp ponds were determined using PC OVERLAY's BUFFER and CLIP commands.

Impacts of shrimp farming on soil resources

To assess the impacts of shrimp farming on soil resources, a shrimp farm, situated at Tambon Kootao in Hat Yai District (7º 06/ N and 100º 27/ E), was selected as a study site. The site, previously devoted to rice cultivation, is located adjacent to Khlong U-Taphao river approximately 25 km inland from the coast. To enable a direct comparison between soils "before" and "after" shrimp farming, soil samples were taken from pond bottoms and original soils in adjacent rice fields. These soils are designated as farmed soils and pre-farmed soils respectively in this study. According to the Department of Land Development (1973), both farmed soils and pre-farmed soils belong to Rangae series and are classified as Thapto-Histic Tropic Fluvaquents. At each sampling location, three replicate samples of disturbed and undisturbed soils at a depth of 15 cm were collected.

The disturbed soil samples were air-dried, passed through a 2 mm sieve, and analyzed for pH, electrical conductivity, organic matter content, total nitrogen, available phosphorus, exchangeable potassium, and texture. Measurements of pH and electrical conductivity (EC) were made on a 1:5 soil/de-ionized water suspension using a glass electrode, and a conductivity cell and direct reading meter respectively. Soil organic matter content was measured using the Walkley-Black technique (Nelson and Sommers, 1982). The Kjeldahl method was used for the assessment of total nitrogen (Bremner and Mulvaney, 1982). Available phosphorus was measured by the Bray-2 method (Bray and Kurtz, 1945). Exchangeable potassium was extracted using ammonium acetate and determined by atomic absorption spectrophotometry (Thomas, 1982). The particle distribution of each soil sample was determined by the hydrometer method (Gee and Bauder, 1986) and the results are expressed as percentage sand, silt, and clay using the USDA size classification. Bulk densities were measured gravimetrically on three replicate undisturbed cores, with core dimensions of 50 mm in diameter by 50 mm in height. Particle density of the solids was determined by the method of Blake and Hartge (1986). Porosity was calculated from the bulk density and particle density (McIntyre, 1974a). Plant available water was evaluated as the difference in water content held at 0.01 MPa and 1.5 MPa (McIntyre, 1974b). The significance of the differences between farmed soils and pre-farmed soils in regard to chemical and physical properties was evaluated using analyses of variance (ANOVA) and the least significant difference test (LSD) procedures (Gomez and Gomez, 1984). Significance was at the $P = 0.05$ level unless otherwise noted.

In addition, three replicate samples of disturbed soils were taken from the top 15 cm at 0, 20, 40, 60, 80 and 100 meters distances from the culture pond. These samples were analyzed for electrical conductivity (EC) using a conductivity cell and direct reading meter.

Impacts of shrimp farming on water resources

In order to elucidate the impacts of shrimp culture on water resources, three sampling sites were established in proximity to a shrimp pond. The sites included source water from which the water was taken to fill the pond enclosures, pond water in which *Penaeus monodon* was cultivated and receiving water immediately outside the ponds in which pond water was discharged. Samplings were carried out during the fourth months of the growout period. At each sampling location, three replicate water samples were collected in 0.75 litre polyethylene bottles from the middle of the water column. The samples were immediately analyzed for dissolved oxygen (DO) using a dissolved oxygen meter (HACH model DO 175). The rest of the water samples were stored on ice and transferred to the laboratory for further analyses. pH and electrical conductivity (EC) were measured using a microprocessor pH meter (WTW model pH 537) and microprocessor conductivity meter (WTW model LF 137), respectively. Turbidity was determined using a turbidimeter (HACH model 2100). Estimates of total suspended solids (TSS) were obtained from the mass of materials retained on Whatman No. 42 filter paper. Analysis of nitrate nitrogen, orthophosphate, and biological oxygen demand (BOD) was performed by the Department of Aquatic Science, Prince of Songkla University, as per methods outlined in the American Public Health Association (1989).

RESULTS AND DISCUSSION

Areal extent of shrimp farming in Songkla Lake Basin

It was not until the early 1980s that Songkla Lake Basin experienced a substantial growth of the shrimp culture industry (Flaherty *et al*., 1999). In 1982, areas devoted to shrimp farming covered an estimated 3,491 ha, equivalent to 0.47 % of the total area of the basin (Table 1). At that time, the development of shrimp farming was limited to a relatively narrow band of coastal land in Ranote District (Figure 1). This is because large volume of seawater are needed to fill the pond enclosures for raising shrimp and to offset losses from water seepage and evaporation during the growth-period (Szuster and Flaherty, 2000). Over a period of 18 years, from 1982 to 2000, shrimp culture areas dramatically rose from 3,491 ha to 7,799 ha, equivalent to an increase of 123.4 % (Table 1). Given that all of the shrimp ponds in the basin are currently in operation and a hectare of pond yields 6 metric tonnes of shrimp per annum, the basin's shrimp production increased from 20,946 metric tonnes in 1982 to 46,794 metric tonnes in 2000. This represents an annual increase of 1,436 metric tonnes. In 2000, the basin's annual shrimp production accounted for about 19.5 % of the country’s total production. If a typical price for a metric ton of shrimp is $ US 6,950 (C.P. Group, 2000), a total estimate of $ US 325,218,300 can be obtained in 2000. It is interesting to note that a farmer with one hectare of his holding devoted to the shrimp culture would have a gross annual income of $ US 41,700. This is 165 times the income of a typical rice farmer in the basin, assuming that a hectare of rice fields yields 2.34 metric tonnes and a typical price for a metric ton of rice is $ US 108.09 (Office of Agricultural Economics, 2001). This economic analysis of shrimp production, however, does not take into account its long-term adverse social and environmental impacts associated with the farming activity (Flaherty *et al*., 2000).

In 2000, it was found that new cultivation areas have emerged along the estuaries of the main rivers some distance upstream from the coast and/or the Songkhla lakes (Figure 2). The establishment of shrimp farming in the basin's freshwater environment has occurred as a result of outbreaks of disease along the coast and the development of low salinity culture techniques for shrimp cultivation (Flaherty *et al*., 2000). The growth of low-salinity shrimp culture in freshwater areas, which is referred to as inland shrimp farming in this paper, has generated widespread concern over the degradation of soil and water resources in the areas of operation.

Coincident with an increase in shrimp culture areas has been a decrease in rice growing areas and mangrove forests. Indeed, between 1982 and 2000, mangrove forests in the basin declined from 3,221 ha to 406 ha, which represents a decrease of 87.4 % (Table 1). Hussain (1995) reported that large areas of mangrove forests in the South China Sea countries have already been converted into shrimp farms and the process is continuing. The depletion of mangroves contributes to the loss of habitat and nursery area for aquatic species as well as reduces shoreline stability during storms (IUCN, 1983; Field, 1995). Likewise, rice growing areas also reduced from 208,599 to 164,209 ha, representing a decrease of 21.3 %. It should be noted, however, that the biggest changes in land use in Songkla Lake Basin between 1982 and 2000 were in forested and rubber areas (Table 1).

An overlay of land use coverage for 1982 with that for 2000 revealed that 3,347 ha, or 77.7 % of the increase in shrimp farm areas in 2000, came from rice fields in 1982 (Table 2). The establishment of shrimp culture operations in the rice growing areas of southern Thailand has generated widespread concern over the salinization of rice fields adjacent to culture ponds (Flaherty *et al*., 1999).

It has been reported that seepage of saline water and discharge of pond effluents can increase salinity level in soils up to 100 meters from the edge of the shrimp ponds (MOSTE, 1999). If the soils within 50 meters radius of the ponds are taken as affected areas, it can be estimated through the use of PC OVERLAY commands in PC ArcInfo that soil subject to salinization impacts was 2,271 ha (Table 3). Further analysis also revealed that 1,127 ha, equivalent to 49.6 %, of the affected soils, is rice fields. In addition, if the soils within 100 meters radius of the pond are taken as affected areas, land area subject to salinization is increased to 4,138 ha (Table 3), of which 1,977 ha, or 47.8 %, of the affected areas is rice fields. If the figure of 1,977 ha is taken as the affected rice fields, then 4,626 metric tonnes of rice, equivalent to a value of approximately $ US 500,024 would have been lost through salinization of soils, assuming a hectare of rice fields yields 2.34 metric tonnes and the price for a metric ton of rice is $ US 108.09. It should be noted that productivity losses due to salinization effects on soils may last several years.

Impacts of shrimp farming on soil resources

Chemical and physical characterization of the pre-farmed and farmed soils was conducted to allow a comparison between the two soils in regard to their properties as well as to define potential limitations to plant growth in these soils. The pH values for both pre-farmed and farmed soils were 4.30 and 4.98, respectively (Table 4). The possible reasons for this could be that the culture ponds were built on sites where soils are acid sulfate soils. The low pH levels in these two soils may have resulted from sulfuric acid generated by exposed pyrite. Acidity of pond bottom soils may subsequently reduce the pH of the pond water (Zweig *et al*., 1999; Boyd and Zimmermann, 2000) which, in turn, reduces growth and survival of cultured shrimps and decreases natural food production (algae growth) within the culture ponds (Poernomo and Singh, 1982). Generally, lime is applied to the pond bottom soils to raise the alkalinity of pond water, thereby removing carbon deficiencies, which limit phytoplankton growth (Boyd and Bowman, 1997). Hence, the significantly greater pH in farmed

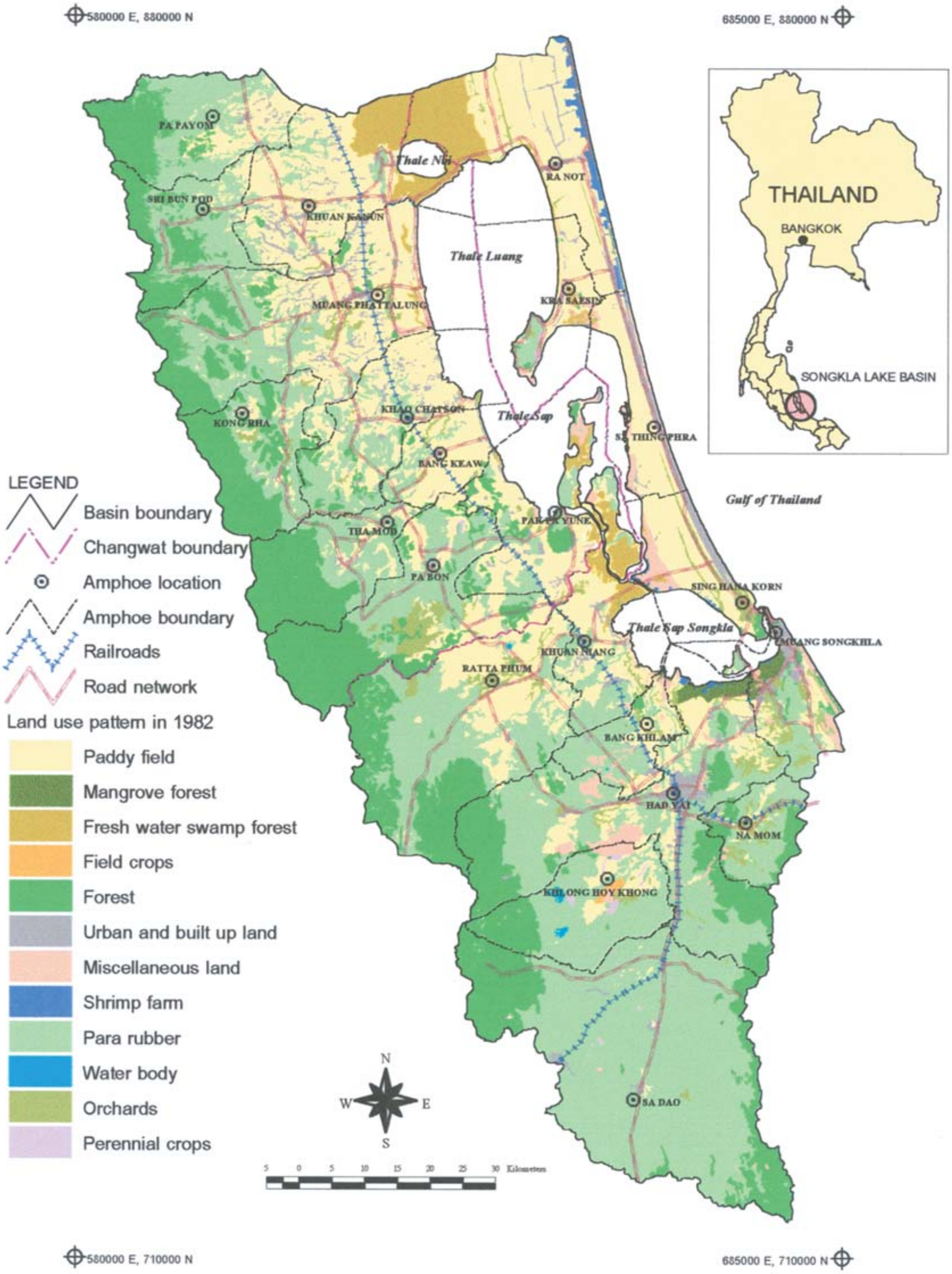

Figure 1 Land use map of Songkla Lake Basin in 1982.

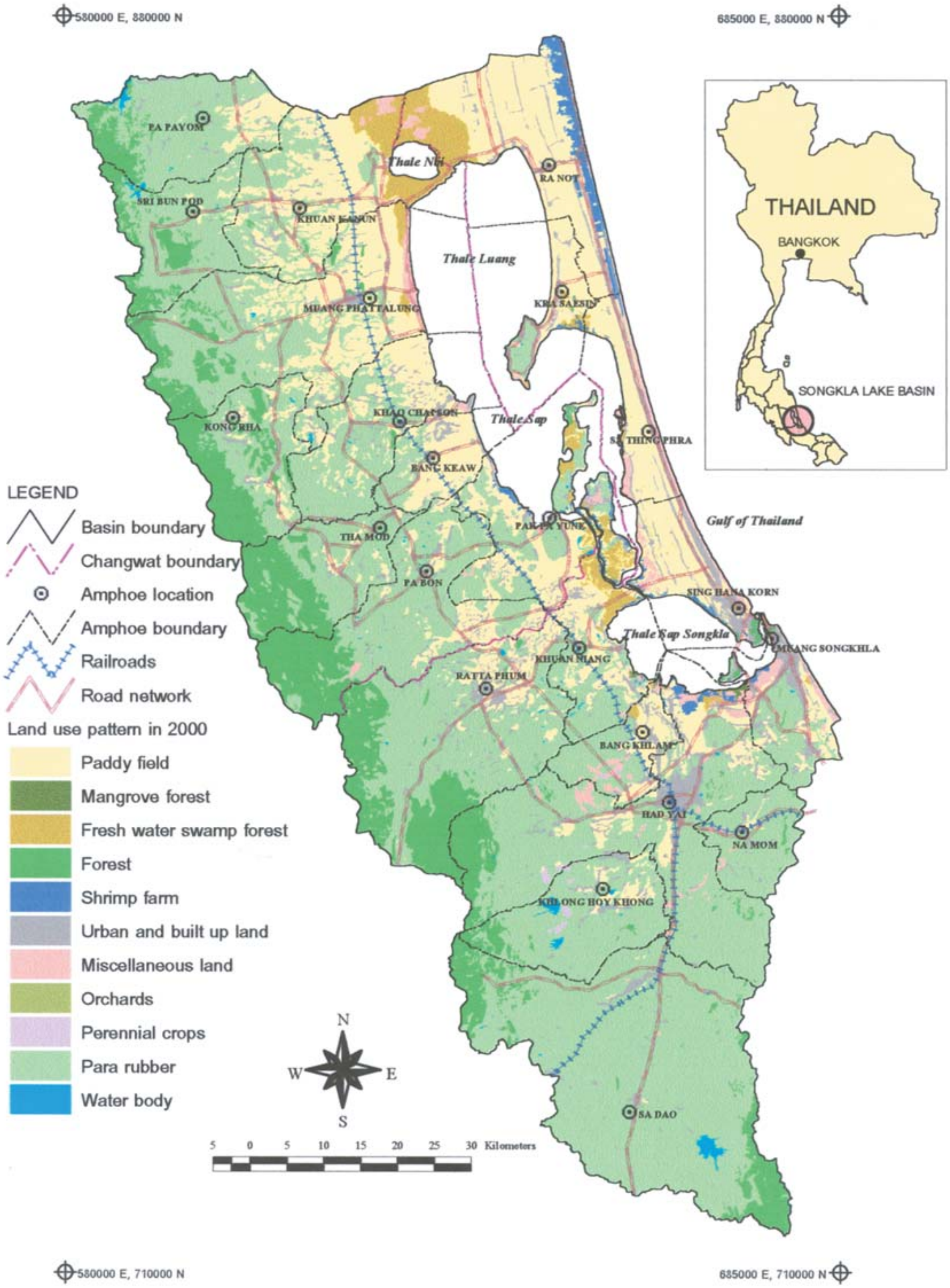

Figure 2 Land use map of Songkla Lake Basin in 2000.

soils compared with that in pre-farmed soil can be explained by this. The EC is recognized as a useful parameter for appraising soil salinity in relation to plant growth. High salinity inhibits plant growth by reducing the osmotic pressure gradient between the plant and soil solutions, restricting the ability of the plant to take up water (Moore, 1998). It should be noted that the EC value for the farmed soils was significantly higher compared to levels in the pre-farmed soils (Table 4), most likely as a result of deposition and accumulation of salts from seawater that are brought in to support the operation of the shrimp farms (Szuster and Flaherty, 2000). With EC value higher than the suggested critical value of 1.6 mS/cm, plants grown on the farmed soils would be restricted by soluble salt (Hunt and Gilkes, 1992). This finding is consistent with the work of Szuster and Flaherty (2000) who reported that salinization can occur through the deposition and accumulation in salts in soils located immediately beneath the pond enclosure.

The salinization effects on soils in the vicinity of shrimp farm were also evident in this study. As seen in Table 5, salinity levels in soils located within 0, 20, 40, 60, 80 and 100 meters distance from the edge of the culture pond were high and well above the suggested critical value of 1.6 mS/cm, indicating that soluble salt levels within these soils limit plant growth. High salinity levels in these soils could be attributed to the seepage of saline water from the culture ponds and/or the discharge of saline pond effluents directly into adjacent waterbodies as well as land areas immediately adjacent to the ponds (Szuster and Flaherty, 2000). In addition, shrimp farmers often remove accumulated sediment deposits that remain on the pond bottoms after harvest and dispose to vacant lands in the vicinity of shrimp farms (Miller *et al.*, 1999). Salt leaches from this sediment can salinize nearby soil and groundwater resources (Boyd and Tucker, 1998). However, the distance of the salt-affected areas from the ponds should be assessed with caution. This is because the physical properties of soils that influence the volume and

Table 1 Estimates of land use and land use change in Songkla Lake Basin between 1982 and 2000.

Land use categories	Area* (ha)		
	1982	2000	Change
1. Forest	146,568	86,225	- 60,343
2. Rubber	292,610	404,531	+ 111,921
3. Rice field	208,599	164,209	- 44,390
4. Fruit orchards	21,412	126	- 21,286
5. Perennial crops	1,196	881	- 315
6. Shrimp farming	3,491	7,799	+4,308
7. Mangrove forest	3,221	406	- 2,815
8. Fresh water swamp forest	24,821	18,682	- 6,139
9. Miscellaneous	7,725	1,908	- 5,817
10. Water bodies	1,334	2,632	+ 1,298
11. Urban / built up area	30,990	54,568	+ 23,578
Total	741,967	741,967	

* excludes lake surface

rate of water flow through soil pores varies spatially (Scott, 2000). However, the high salinity levels of soils in the immediate vicinity of the ponds are of sufficient concern to warrant an initiation of environmentally sound shrimp cultivation practice that reduce concentrations of potential pollutants in pond effluents and/or a closure of all the shrimp ponds operating in freshwater areas. The salinization of soils generated by shrimp cultivation has also been reported by Csavas (1995), Tookwinas *et al*. (!997) and Im-Erb *et al*. (2001).

The organic carbon figure for farmed soils is significantly lower than that for pre-farmed soils (Table 4). The low organic carbon level in farmed soils was likely to be the result of the removal of surface soils that were subsequently used for the construction of pond embankments when ponds are initially constructed. With organic carbon contents lower than 1 %, farmed soils would be expected to have unstable structure (Moore, 1998). Further, the shortage of organic carbon in farmed soils curtails the supply of available nitrogen and phosphorus (Pulford, 1991). Higher content of organic carbon in pre-farmed soils could be attributed to vegetation remains. According to Landon (1991), CEC values for pre-farmed and farmed soils are considered to be medium and low, respectively. The greater organic carbon content in pre-farmed soil accounts, in general, for its high value of CEC.

The total nitrogen in farmed soils, which was significantly lower than that in pre-farmed soils, was lower than the critical level of 0.15 % (Moore, 1998). Likewise, phosphorus concentration in farmed soils falls below the 4 mg/kg minimum threshold (Landon, 1991), suggesting a probable

Table 2 The acreage of land areas under different uses in 1982 that were converted to shrimp farming in 2000.

Year	1982								2000
Land use	Rice	Rubber	Mangrove	Orchards	Shrimp	Swamp	Urban	Miscellaneous	Shrimp
Area (ha)	3,347	161	466	25	2,836	370	267	327	7,799

Table 3 Areas affected by shrimp farming in 2000.

Land use types in 2000	Affected areas (ha)	
	50 meters from pond edge	100 meters from pond edge
1. Rice fields	1,127	1,977
2. Forest	-	-
3. Rubber	83	176
4. Mangrove forests	12	28
5. Fresh water swamp	232	456
6. Urban/built up area	440	805
7. Water bodies	1	4
8. Miscellaneous	376	693
Total	2,271	4,139

deficiency. The higher concentrations of total nitrogen and available phosphorus in pre-farmed soils may have resulted from a combination of the fertilizers and vegetation remains on rice fields The potassium levels in both soils were found to be higher than critical values of 0.15 meq/100 g, and therefore deficiency was unlikely (Landon, 1991). To ensure successful establishment of plants on the farmed soils after cessation of shrimp farming, the shortage of both nitrogen and phosphorus has to be rectified by applying chemical fertilizers, maintaining soil organic matter, and growing nitrogen-fixing species.

The physical characteristics of the soils collected from farmed soils and pre-farmed soils are presented in Table 5. The farmed soils and pre-farmed soils had clay percentage of 31.4 and 57.8 and their textural classes were clay loam and clay, respectively. According to Boyd and Bowman (1997), pond soils should contain 20-30 % clay-size particles to provide a barrier to seepage. Dry bulk density, porosity and hydraulic conductivity are important parameters determining the transport of air and water into the rooting zone (Rowell, 1994). The higher the soil bulk density the more compacted the soil and the lower the porosity (Scott, 2000). The significantly higher bulk density in farmed soils indicated that compaction has occurred, probably as a result of tractor wheel passage under wet field conditions during pond construction (Batey, 1988). Compaction problems in abandoned farmed lands could be a major factor in rehabilitation failure and alleviation requires good mechanical loosening practices. The air-filled porosity of farmed soils was below the critical value of 10 %, indicating that oxygen supply could become limiting to root growth (Mullins, 1991). In addition, farmed soils had lower values of available water percentage than the pre-farmed soils (Table 5), apparently as a result of higher bulk density and lower organic carbon contents. However, the available water values for both soils are above the acknowledged critical threshold value of 12 %, indicating that both soils would retain sufficient moisture in most years to allow satisfactory plant growth. According to Hunt and Gilkes (1992), values of saturated hydraulic conductivity for both soils were considered to be extremely slow, and hence seasonal waterlogging could be a problem in plants grown in these soils.

Laboratory characterization of farmed soils have demonstrated that the practice of inland shrimp farming contributes to the loss of soil quality in the area of operation. The degradation of lands that were used for shrimp production poses a serious threat to the welfare of the local population who are reliant upon this resource for their livelihoods. Since in most cases land which has been made derelict by shrimp farming was in agricultural use, rehabilitation to arable farming after the conclusion of shrimp cultivation is perhaps the most common land use objective. However, the cost of rehabilitating erstwhile farmed lands could be substantial (Department of Land Development, 1999) and may take several years (Bhatta and Bhat, 1998). In this regard, relevant government agencies should support further research studies on farmed land rehabilitation that can be achieved at affordable costs and in a timely manner.

Impacts of shrimp farming on water resources

The properties of source water, pond water, and receiving waters are presented in Table 6. The pH value for pond water was significantly higher than that for source water or receiving waters. The high pH value in pond water could be attributed to the application of lime to raise the pH level of acidic pond water in order to improve survival, reproduction and growth of shrimp (Boyd, 1990; Boyd and Bowman, 1997). According to the water quality standard for coastal aquaculture established by the Department of Fisheries (1994), the ideal pH levels for shrimp cultivation range from 6.5 - 8.5. As seen in Table 6, pond water had a salt content of

4.40 ppt, which was significantly higher than that of the source water. The higher salinity level in the pond water was attributed to seawater added to them to adjust salinity to an optimum level for cultivating shrimp (Tsai, 1989). According to Szuster and Flaherty (2000), the salt levels for the low-salinity shrimp culture should be in the range of 4 to10 ppt. The exchange of pond water with outside water to maintain good water quality and the usual practice of discharging saline pond water directly into adjacent receiving waters at harvest probably accounted for the higher salinity levels in receiving waters compared with the source water.

Pond water turbidity was significantly higher than that for source water or receiving waters. Eroded sediments from the pond sides, uneaten

Table 4 Physical and chemical properties of pre-farmed and farmed soils.

Soil properties	Pre-farmed soils	Farmed soils
1. Chemical properties		
PH	4.30a	4.98b
EC (mS/cm)	0.23a	2.04b
Organic carbon (%)	3.69a	0.26b
CEC (meq/100 g soil)	16.64a	5.71b
Total nitrogen (%)	0.30a	0.10b
Available Phosphorus (mg/kg)	7.23a	1.38b
Exchangeable Potassium (meq/100g soil)	0.26a	0.22a
2. Physical properties		
Texture	Clay	Clay loam
Sand (%)	16.01a	24.89b
Silt (%)	26.18a	43.74b
Clay (%)	57.82a	31.37b
Bulk density (g/cm^3)	1.15a	1.62b
Particle density (g/cm^3)	2.73a	2.76a
Air-filled porosity at field capacity (%)	27.94a	8.14b
Plant available water (%)	16.06a	12.60b
Saturated hydraulic conductivity (m/day)	0.19a	0.01b

*Within a column, means followed by the same letter within each properties are not significantly different at the 0.05 level of significance.

Table 5 Mean electrical conductivity of soils taken from 0, 20, 40, 60, 80 and 100 meters distances from the edge of the culture pond. Numbers in brackets represent Standard Deviation.

Distance from pond edge	0 m	20 m	40 m	60 m	80 m	100 m
Electrical conductivity (mS/cm)	5.24 (0.08)	4.42 (0.01)	5.10 (0.01)	4.05 (0.01)	5.65 (0.01)	5.10 (0.02)

feed and plankton probably accounted for the higher turbidity values of the pond water (Boyd *et al*., 1994). The turbidity value of pond water was high and well above the maximum permissible concentrations of 400 mg/l recommended by Chaiyakam and Predalumpabut (1994), indicating high pollution potential of discharge from the ponds. DO value for pond water was significantly higher than that for source water or receiving waters (Table 6). The DO value for pond water was high and well above the required minimum of 4.0 ppm (Department of Fisheries, 1994). This was likely the result of the use of paddlewheel aerators to maintain the pond's optimum oxygen level (Department of Fisheries, 1999). BOD concentrations for pond water were significantly higher than that for source water (Table 6), most likely due to the decay of uneaten feed, vegetation and plankton (Lee, 1997) and plankton respiration (Seim, *et al*., 1997). Even though receiving waters had significantly lower BOD concentrations than pond water, its BOD value exceeded the acceptable limits of 10 mg/l recommended by the Department of Fisheries (1994). Assimilative capacity of receiving waters and flush by the wet season flood probably accounted for the significantly lower BOD value in receiving waters compared to value in the pond water (Predalumpaburt and Chaiyakam, 1994). It should be noted that high concentrations of BOD in pond water and receiving waters found in this study are similar to those reported by Pongthanapanich (1999).

The TSS values for pond water and receiving water were significantly higher than that for source water (Table 6). The major sources of suspended solids in pond water and pond effluents are suspended soil particles and particulate organic matter resulting from live plankton and detritus (Boyd and Tucker, 1998). The observed increment in the TSS values in receiving waters compared to that in source water was probably a direct consequence of the discharge pond effluents. The concentrations of nitrate in pond water were significantly higher than the corresponding values for source water (Table 6). Similarly, a significantly higher concentration of orthophosphate was also recorded in pond water, compared with the source water. Elevated levels of these two nutrients in the pond water were most likely a result of the fertilizers applied, decomposed feeds and faecal matter in the culture ponds (Boonsong and Eiumnoh, 1995; Bhatta and Bhat, 1998). However, concentrations of nitrate and orthophosphate recorded in pond water and receiving waters were quite low (Chaiyakam and Predalumpabut, 1994; Boyd and Tucker, 1998), indicating that eutrophication and excessive growth of algae and aquatic plants may not be a problem (Zweig *et al*., 1999; Boyd and Zimmermann, 2000).

It is apparent from the water analyses that shrimp farming activities deteriorated the quality of waterbodies in close proximity to the culture ponds, most likely through the discharge of saline pond effluents rich in TSS and BOD during water exchange to maintain the growing environment, and draining of grow-out ponds at harvest. Deterioration in the quality of waterbodies could affect options for crop irrigation (Dierberg and Kiattsimkul, 1996) and generate conflicts in resource use between rice farmers and shrimp producers (Szuster and Flaherty, 2000). In addition, water quality deterioration could contribute to outbreaks of disease which, in turn, result in a catastrophic collapse of the industry (Corea *et al*., 1998).

In conclusion, the results of the present study have clearly indicated that the expansion of inland shrimp farming in the Songkla Lake Basin, while bringing considerable economic benefits, has also brought about environmental and social costs. Shrimp culture operations perturb the long-term viability of the basins biophysical environments, primarily through the losses of soil and water quality. The seawater added to the culture ponds to obtain suitable pond salinity level for raising shrimp increased soluble salt levels of pond bottom soils. In addition, seepage of saline water from the culture ponds raised salinity levels of surface soils in the immediate vicinity of the ponds beyond tolerable limits for crop production, generating conflicts with the rice farmers. Moreover, the release of large quantities of untreated pond effluents directly into waterbodies in close proximity to the culture ponds causing deterioration of its quality. The perturbation in the freshwater environment and the conflicts in resource use between rice farmers and shrimp producers that occur pose a direct threat to the welfare of the local population. Thus, the practice of inland shrimp farming must be prohibited in order to restore the right to a healthy environment and the livelihood of current as well as future generations of the basin's population.

Approaches to the problem

To address the expansion of inland shrimp farming that threatened the environmental sustainability, the Royal Thai Government imposed the ban on shrimp farming in the country's freshwater areas in July 1998 (National Statistical Office, 1999; Miller *et al*., 1999). Moreover, the Department of Land Development has created a zoning map to designate fresh water areas where shrimp farming is not permitted (Anecksamphant, 2001). With this zoning plan, relevant government departments would be able to oversee and control inland shrimp cultivation in order to mitigate its impacts on the freshwater environment. However, the effort to enforce the zoning plan by the government departments has been largely ineffective (Szuster and Flaherty, 2000). This has allowed the small-scale shrimp farmers, who believe that shrimp culture provides a means by which they can obtain farm incomes many times higher than that provided by rice farming, to operate in the freshwater areas using culture practices that degrade the soil and water environments. The enforcement capacity of responsible agencies must, therefore, be strengthen through increased budget and personnel, improved technologies such as Geographic Information Systems and remote sensing, and better coordination between local government agencies. In addition, it should be recognized that the most crucial points in making the zoning plan successful is the full and active participation of the general public, Tambon

Table 6 Water properties in source water, pond water and receiving waters.

Properties	Source water	Pond water	Receiving water
pH	6.61a	8.77b	6.84a
Salinity (ppt)	0.10a	4.40b	4.47b
Turbidity (NTU)	38.77a	70.83b	16.67c
DO (mg/l)	4.53a	6.52b	5.16c
BOD (mg/l)	4.00a	26.33b	13.67c
TSS (mg/l)	336.67a	5,860.00b	6,283.33b
Nitrate (mg/l)	0.009a	0.188b	0.005a
Orthophosphate (mg/l)	0.018a	0.028b	0.024a

- Within a column, means followed by the same letter within each property are not significantly different at the 0.05 level of significance.

Administration Organization, NGO and local farmers in the planning, implementation and refinement of this zoning plan. Cooperative and collaborative relationship with these parties will help ensure the protection of the soil and water quality in freshwater areas that represent the agricultural heartland of the Songkla Lake Basin.

Of equal importance to the zoning plan is an improvement in shrimp producers' awareness of the adverse environmental impacts that inland shrimp farming could have on their communities and/or on their own production in return. The development of public awareness programme to educate, inform and warn shrimp raisers about the potential environmental consequences of shrimp farming would be one the critical elements for longer-term environmental stability and sustainability of the culture industry in the Songkla Lake Basin.

ACKNOWLEDGEMENTS

The authors are grateful to anonymous referees for their constructive perusal on an earlier version of this manuscript.

LITERATURE CITED

American Public Health Association. 1989. Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Washington, DC. 1268 p.

Anecksamphant, C. 2001. Impact of inland shrimp farming on soil resources and rehabilitation measures. Paper presented at an annual meeting of the Soil and Fertilizer Society of Thailand. Bangkok. 24 p. (In Thai).

Batey, T. 1988. Soil Husbandry. Aberdeen University Press. Aberdeen. 157 p.

Bhatta, R. and M. Bhat, 1998. Impacts of aquaculture on the management of estuaries in India. Environmental Conservation 25 (2) : 109-121.

Blake, G.R. and K.H. Hartge, 1986. Bulk density, pp. 363-375. *In* A. Klute (ed.). Methods of Soil Analysis. Part 1. Physical and mineralogical Methods. 2nd ed., Agronomy monograph no. 9. American Society of Agronomy, Inc. Madison, Wisconsin.

Boonsong, K. and A. Eiumnoh. 1995. Integrated management system for mangrove conservation and shrimp farming: A case of Kung Krabaen Bay, Chanthaburi Province, Thailand, pp. 48-66. *In* Choob Khemnark (ed.). Proceedings of the ECOTONE IV: Ecology and Management of Mangrove Restoration and Regeneration in East and Southeast Asia. Surat Thani.

Boyd, C.E. 1990. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station. Auburn University. Birmingham Publishing Co. Alabama. 482 p.

Boyd, C.E. and Bowman, J.R. 1997. Pond bottom soils, pp. 135-162. *In* H.S. Egna and C.E. Boyd (eds.). Dynamics of Pond Aquaculture. CRC Press. New York.

Boyd, C.E. and C.S. Tucker, 1998. Pond aquaculture water quality management. Kluwer Academic Publishers. Boston, U.S.A. 700 p.

Boyd, C.E. and S. Zimmermann. 2000. Grow-out systems - water quality and soil management, pp. 221-238. *In* M.B. New and W.C. Valenti (eds.) Freshwater Prawn Culture. Blackwell Science Ltd. United Kingdom.

Boyd, C.E., P. Munsiri, and B.F. Hajek, 1994. Composition of sediment from intensive shrimp ponds in Thailand. World Aquaculture 25 : 53-55.

Bray, R.H. and L.T. Kurtz, 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59 : 39-45.

Bremmer, J.M. and C.S. Mulvaney, 1982. Nitrogen-Total, pp. 595-624. *In* A.L. Page (ed.) Method of Soil Analysis. Part 2. Chemical and Microbiological Properties. 2nd ed., Agronomy Monograph no. 9. American Society of Agronomy, Inc. Madison, Wisconsin.

Chaiyakam, K. and Y. Predalumpabut. 1994. Measures to Reduce Environmental Impacts of Shrimp Farming. National Institute of Coastal Aquaculture. Department of Fisheries. 27 p. (in Thai).

Chin, K.K. and Ong, S.L. 1997. Water conservation and pollution control for intensive prawn farms. Water Science and Technology 35(8) : 77-81

Corea, A., R. Johnstone, J. Jayasinghe, S. Ekaratne, and K. Jayawardene, 1998. Self-pollution: A major threat to the prawn farming industry in Sri Lanka. Ambio. 27 (8) : 662-668

C.P. Group. 2000. Shrimp Culture Newsletter. November, 2000. 4 p.

Csavas, I. 1995. Development of shrimp farming with special reference to Southeast Asia. Fishing Chimes. 15 (1) : 33-43

Danish Cooperation for Environment and Development and Ministry of Science, Technology and Environment. 1998. Environmental and Socio-Economic Profile. The EMSONG Project. Technical Background Report No. 21. VKI in association with DHI, PEM consult A/S, COWI A/S, Prince of Songkla University and Seatec International Ltd., Songkhla 90 p.

________. 1999. Water resources management in the Songkla Lake Basin. The EMSONG Project. Technical Background Report No. 18. VKI in association with DHI, PEM consult A/S, COWI A/S, Prince of Songkla University and Seatec International Ltd., Songkhla. 109 p.

Department of Fisheries. 1994. Water qualities for coastal aquaculture. Principles and analytical methods. National Institute of Coastal Aquaculture. Department of Fisheries. Ministry of Agriculture and Cooperatives. Bangkok. 110 p.

Department of Fisheries. 1999. Biotechnology for Intensive Marine Shrimp Farming along the Code of Conduct. 19 p.

Department of Land Development. 1973. Soil Map of Songkla Province. Province series no. 18. Ministry of Agriculture and Cooperatives, Bangkok.

Department of Land Development. 1999. Rehabilitating land effected by shrimp farming in freshwater areas. Ministry of Science, Technology and Environment. Bangkok, Thailand. (in Thai).

Dierberg, F.E. and W. Kiattisimkul. 1996. Issues, impacts, and implications of shrimp aquaculture in Thailand. Environmental Management 20 (5) : 649-666

Environmental Systems Research Institute. 1998. PC ARC/INFO User guides. Environmental Systems Research Institute, Inc. Redlands.

Field, C. D. 1995 Journey amongst mangroves. The International Society for Mangrove Ecosystems (ISME). Okinawa. 140 p.

Flaherty, M. and C. Karnjanakesorn. 1995. Marine shrimp aquaculture and natural resource degradation in Thailand. Environmental Management 19 (1) : 27-37

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

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

Gee, G.W. and J.W. Bauder. 1986. Particle-size analysis. p. 383-411. *In* A. Klute (ed.). Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. 2nd ed., Agronomy monograph no. 9. American Society of Agronomy, Inc. Madison, Wisconsin.

Gomez, K.A. and Gomez, A. A. 1984. Statistical Procedures for Agricultural research. 2nd ed., John Wiley and Sons. New York. 676 p.

Hunt, N. and B. Gilkes. 1992. Farm Monitoring Handbook. The University of Western Australia. Australia. 280 p.

Hussain, Z. 1995. A review of the status of mangroves in the South China Sea countries, pp. 194-203. *In* Proceedings of a Workshop on Coastal and Marine Environmental Management. An Asian Development Bank Publication. Manila.

Im-Erb, R., P. Yamclee, S. Prosayakul, P. Tanprapas and P. Pongwichian. 2001. Giant tiger shrimp cultivation and tha salinization of arable land in Thailand. *In* E.M. Bridges, I.D. Hannan, L.R. Oldeman, F.W.T. Penning de Vries, S.J. Scherr and S. Sombatpanit (eds.). Response to Land Degradation. Science Publishers, Inc. Plymouth.

International Union for Conservation of Nature and Natural Resources. 1983. Global Status of Mangrove Ecosystems. Commission on ecology papers no. 3. P. Saenger, E.J. Hegerl and J.D.S. Davie (eds.) International Union for Conservation of Nature and Natural Resources. 87 p.

Landon, J.R. 1991. Booker Tropical Soil Mannual. Longman Scientific and Technical. Essex, England. 474 p.

Lee, J.S. 1997. Aquaculture - An Introduction. AgriScience and Technology series. Interstate Publishers, Inc. Illinois, 518 p.

Lesaca, R.M. 1977. A Proposed Programme of Resources Management of Lake Songkhla Watershed. UNEP Regional Office for Asia and the Pacific. Bangkok. 78 p.

McIntyre, D.S. 1974a. Pore-space and aeration determinations, pp. 67-74. *In* J. Loveday (ed.). Methods for Analysis of Irrigated Soils. Technical Communication No. 54. Commonwealth Bureau of Soils. Commonwealth Agricultural Bureaux. Bucks.

McIntyre, D.S. 1974b. Water retention and moisture characteristics, pp. 43-62. *In* J. Loveday (ed.). Methods for Analysis of Irrigated Soils. Technical Communication No. 54. Commonwealth Bureau of Soils. Commonwealth Agricultural Bureaux. Bucks, England.

Miller, P.J., M. Flaherty, and B. Szuster. 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 Fresh Water Areas. Committee on inland shrimp farming. Ministry of Science, Technology and Environment. Bangkok. (in Thai)

Moore, G. 1998. Soilguide. A handbook for understanding and managing agricultural soils. Bulletin 4343. Natural Resource Management Service. Agriculture Western Australia. 331 p.

Mullins, C.E. 1991. Physical properties of soils in urban areas, pp. 87-118. *In* P. Bullock and P.J. Gregory (eds.). Soils in the Urban Environment. Blackwell Scientific Publications. Oxford, Great Britain.

National Statistical Office. 1999. Brackishwater Shrimp Culture Development in Thailand during 1985-1995. Office of the Prime Minister. Thailand. 68 p.

NEDECO. 1972. Report on the Preliminary Survey of the Thale Sap Basin Project. Netherlands Engineering Consultants. 65 p.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter, pp. 539-579. *In* A.L. Page (ed.) Method of Soil Analysis. Part 2. Chemical and microbiological properties. 2nd ed., Agronomy Monograph no. 9. American Society of Agronomy, Inc. Madison, Wisconsin.

National Economic and Social Development Board and National Environment Board. 1985. Songkhla Lake Basin Planning Study. Final report. Vol. 2 : Main report. John Taylor and Sons, REDECON Australia Pty. Ltd., Asian Engineering Consultants Corp. Ltd., Roger Tym and Partners, National Environment Research Council, and Team Consulting Engineers Co. Ltd. Bangkok. 349 p.

Office of Agricultural Economics. 2001. Agricultural statistics of Thailand. Agricultural statistics no. 9/2001. Ministry of Agriculture and Co-operatives, Bangkok. 151 p.

Phillips, M. and Barg, U. 1999. Experiences and opportunities in shrimp farming, pp. 43-72. *In* N. Svennevig, H. Reinertsen and M. New (eds.) Proceedings of the Second International Symposium on Sustainable Aquaculture, Oslo.

Poernomo, A. and V.P. Singh. 1982. Problems, field identification and practical solutions of acid sulfate soils for brackishwater fishponds, pp. 49-61. *In* Report on Consultation and Seminar on Coastal Fishpond Engineering. South China Sea Fisheries Development and Coordinating Programme. Manila.

Pongthanapanich, T. 1999. Inland shrimp farm: How profitable, what really are their impact on the environment, is inland shrimp farming worth a second look?. Aquaculture Asia 4 (1) : 33-36

Predalumpaburt, Y. and K. Chaiyakam. 1994. Impacts of shrimp farm effluent on receiving water qualities. Technical paper no. 7/1994. National Institute of Coastal Aquaculture. Songkla, Thailand. 39 p. (In Thai).

Pulford, I.D. 1991. Nutrient provision and cycling in soils in urban areas, pp. 119-138. *In* P. Bullock and P.J. Gregory (eds.). Soils in Urban Environment. Blackwell Scientific Publications. Oxford.

Rowell, D.L. 1994. Soil Science; Methods and Applications. Longman Scientific and Technical. Essex, England. 350 p.

Scott, H.D. 2000. Soil Physics. Agricultural and Environmental Applications. Iowa State University Press. Iowa, U.S.A. 421 p.

Seim, W.K., C.E. Boyd, and J.S. Diana. 1997. Environmental considerations, pp. 163-182. *In* H.S. Egna and C.E. Boyd (eds.). Dynamics of Pond Aquaculture. CRC Press, New York.

Szuster, B.W. and M. Flaherty. 2000. Inland low-salinity shrimp farming in the central plains region of Thailand, pp. 1-11 *In* International Conference. The Chao Phraya Delta: Historical Development, Dynamics and Challenges of Thailand's Rice Bowl. Kasetsart University, Bangkok.

Tanavud, C., C. Yongchalermchai, and A. Bennui. 1999. Land use zoning in Songkla Lake Basin using GIS and remote sensing technologies. Thai Journal of Agricultural Science 32 (4) : 557-573

Tanavud, C., M. Kimura, C. Yongchalermchai, M. Komamura, and A. Bennui. 2000. Effects of land use patterns on ecosystems in Thailand: Land use changes and its environmental consequences in Songkla Lake Basin, pp. 39-56. *In* Aran Patanothai (ed.). Proceedings of the International Seminar on Japan-Southeast Asian Agricultural Research Cooperation: Past Accomplishments and Future Needs (JSARC). Khon Kaen University. Khon Kaen, Thailand.

Thimakorn, P. and S. Vongvisessomjai. 1979. Effect of Channel Dredging on Discharge Pattern and Salinity Distribution of Songkla lagoon. Vol. 2. Main report. Asian Institute of Technology. Bangkok. 91 p.

Thomas, G.W. 1982. Exchangeable cations, pp. 159-165. *In* A.L. Page (ed.) Method of Soil Analysis. Part 2. Chemical and microbiological properties. 2nd ed., Agronomy Monograph no. 9. American Society of Agronomy, Inc. Madison, Wisconsin.

Tookwinas, S., R. Tabkaew, and P. Srisapoom. 1997. An intensive marine shrimp culture in freshwater area (Suphanburi Province): The preliminary investigation on impact assessment. Thai Fisheries Gazette 50 (2) : 153-164

Tsai, C.K. 1989. Water quality management, pp. 56-63. *In* Proceedings of the Southeast Asia shrimp farm management workshop. American Soybean Association. St. Louis.

Zweig, R.D., J.D. Morton, and M.M. Stewart. 1999. Source Water Quality for Aquaculture: A Guide for Assessment. The World Bank. Washington, D.C. 62 p.

Received date : 8/08/01
Accepted date : 28/09/01