IMPACTS OF SHRIMP FARMING ON THE SOCIO-ECONOMIC AND ENVIRONMENTAL SITUATION IN THE COASTAL CAI NUOC DISTRICT, MEKONG DELTA, VIETNAM

Dao Kim Nguyen Thi Binh, Nguyen Tho, Nguyen Thanh Hung
Sub-Institute of Geography in HCMC, Vietnamese Academy of Science and Technology
01 Mac Dinh Chi Street, District 1, Ho Chi Minh City, Vietnam
pvdialy@hcm.vnn.vn

Nico Vromant
Katholieke Universiteit Leuven, Laboratory of Aquatic Ecology
Charles de Bériotstraat 32, B-3000 Leuven, Belgium
nico.vromant@tiscali.be

Frans Ollevier
Laboratory of Aquatic Ecology, Katholieke Universiteit Leuven
Charles de Bériotstraat 32, B-3000 Leuven, Belgium
aquabio@bio.kuleuven.ac.be

Ann Sels, Luc Hens, Emmanuel Boon
Vrije Universiteit Brussel, , Human Ecology Department
Laarbeeklaan 103, B-1090 Brussels, Belgium
human.ecology@vub.ac.be

Abstract: Shrimp farming is gradually changing the coastal landscape of many Asian countries. This paper examined the impacts of shrimp farming on the environment (mangrove forest, surface water, and soil) and socio-economic characteristics (loans, education and health) of a coastal district, Cai Nuoc, in the Mekong delta, Vietnam. Aerial photographs (1968 & 1992) and satellite images (1997/98 & 2003) were compared to chart land use changes. Surface water and soil were sampled, and a socio-economic survey was organized. The land use patterns in the district had changed dramatically. The mangrove forest which, in 1968, covered 25% of the area had nearly disappeared. Between 1998 and 2003, land use swapped from rice-based farming systems to shrimp monoculture. This resulted in an increased salinisation and organic pollution of the surface water. The increased salinisation of soil was found. The shrimp farmers accumulated debts that resulted in increased food insecurity and a drop in primary school attendance.
Keywords: Impact, land use, farmers, shrimp farming, salinity

1. Introduction

The movement to greater liberalization of trade is bringing increased pressure for the restructuring of agriculture from traditional, low value crops, such as rice, to capital-intensive, high value crops, such as shrimp [1]. However, the cost of cultivating shrimp is higher than the average consumer ever dreamed of [2] as the rapid expansion and intensification of shrimp production has generated widespread concern over the industry's environmental, social and financial impact [3-5]. The shrimp industry is known to degrade coastal ecosystems and has high social and economic costs that are being passed on to the rural poor [6-8].

Vietnam is the world's seventh largest shrimp producer, with an average world market share of about 3%. Extensive shrimp farming started in the Mekong delta soon after the end of the war against the USA [9]. From 2000 onwards, shrimp monoculture developed at a very fast rate, especially in the coastal areas of the Mekong Delta where 260,000 ha of land was used for shrimp aquaculture in the year 2002 [10]. In 2004, Ca Mau, the southernmost province of Vietnam's Mekong Delta, was good for 250,000 ha of shrimp lands [11]. In a very short time span, the area underwent dramatic land use changes, from a rice based land use system to a shrimp monoculture land use system [10].

The aim of this research is to determine the impact of these land use changes on selected environmental (surface water, soil, and mangrove forests) and socio-economic parameters (loans, education and health) in the Cai Nuoc district, Ca Mau province.

2. Materials and methods

The 521,084 ha Ca Mau province is the most southern province of Viet Nam. It combines a rapidly growing population with a fast expanding shrimp farming industry, good for 202,000 ton year^{-1} and about 45% of Vietnam's total shrimp production [12]. The 835 km^2 Cai Nuoc district (Fig. 1) is situated in the South-West of Ca Mau province, Mekong Delta, Vietnam. The Cai Nuoc area is a lowland delta plain with an average elevation of 0.2 m. A dense network of rivers and canals connects to both the East Sea and the Gulf of Thailand. Consequently the Cai Nuoc district is affected by the tides from both seas. The highest salinity (22 to 32 g l^{-1}) in the study area occurs in April [13]. During the wet season, there is no salt intrusion as there is a large freshwater input through precipitation. However, during the dry season, freshwater input is low and evaporation is intense. The district is affected by salinity for over 6 months [14].

To detect land use changes in the Cai Nuoc district, aerial photographs of the year 1968 and 1992, and satellite images for the years 1997/98 and 2003 have been used. A U.S army map (3 December 1969; 3rd edition; scale 1/50,000) was used as the topographic base map. For the 1968 land use data, 58 aerial photographs (U.S army; scale 1/25 000; horizontal covering 60%; vertical covering 30%) were used. For the 1992 land use data, 154 pictures were used (Vietnamese Ministry of Defence; scale 1/22,000; horizontal covering 60%; vertical covering 30%). The 1997/98 land use data were derived from two Spot 4 images. For the 2003 land use data, two Landsat 7 ETM+ images were used. Photographs and satellite images were analysed for land use patterns. Elsewhere, the analysis methodology is discussed in detail [10].

The surface water was sampled at 35 sites (14 in canals and 21 in shrimp ponds), randomly spread over the Cai Nuoc district. For each sampling point, the shortest distance to the Gulf of Thailand was calculated as it was hypothesised that the surface water quality differed with the distance to sea. All sites were sampled four times: (a) wet season 2002, (b) dry season 2003, (c) wet season 2003, and (d) dry season 2004, following the Vietnamese standard procedure [15]. Electric conductivity (EC), salinity, DO, and pH were measured in the field (with an EC-meter (SCM 2000A), a salinity meter (SM–802, APEL), a DO-meter (Oxi 330i), and a pH-meter (pH 62K, APEL), respectively). The other variables were measured in the laboratories of the Sub-Institute of Geography in Ho Chi Minh City, following the procedures described in the Vietnamese standard 5942-1995 (15). This includes: (i) Chloride: Mohr method, (ii) Sulfate: Turbidity method, (iii) Chemical Oxygen Demand (COD): Dichromate method, (iiii) Nitrate (NO_3^-): Brucine method, (v) Ammonium (NH_4^+): Nessler method, and (vi) Phosphate (PO_4^{3-}): $SnCl_2$ method. The data set contained 140 entries (35 sampling sites x 4 seasons) and was analysed with ANCOVA (independent variables: time and water source; continuous variable: distance to sea). Significant differences between the levels of the independent variables were analysed with the Tukey Honest Significant Difference test. All significance testing was done at the 0.05 level.

The 25 sampling sites for soil study were randomly spread over the Cai Nuoc district and sampled for four seasons as for the surface water, following the prescripts of the Vietnamese Soil Association [16]. At each sampling site, a 1 kg sample of all the available (4 to 6) layers was collected in polyethylene bags, with 3 replicas. All the analyses were performed in the laboratories of the Sub-Institute of Geography in Ho Chi Minh City: (1) pH: pH-meter (1/2.5)(w/v), (2) $EC_{(1/5)}$: EC-meter (1/5)(w/v) and converted to 25^{0}C, (3) soluble sulfate: Turbidity method, (4) Cl^-: Mohr method, (5) soluble and exchangeable cations (Ca, Mg, Na, K): AAS. The parameter EC_e (EC of the saturated extract) was calculated as 6.4 times larger than $EC_{(1:5)}$) [17]. The data set contained 405 entries and was brought to ANOVA analysis, which "season" acted as independent (categorical) variable and 13 other parameters (pH, $EC_{(1/5)}$, EC_e, Cl^-, soluble SO_4^{2-}, soluble and exchangeable cations (Ca, Mg, Na, K)) as dependent variables. Significant differences between the levels of the categorical variable were further analyzed with the Tukey Honest Significant Difference test for post-hoc mean's comparison. All significance testing was done at the 0.05 level.

2.5. Socio-economic Analysis

Around the sampling points of water and soil, 80 farm households, totalling 461 household members, were selected at random, and surveyed between 4 and 14 September 2003. Farmers were asked how their farming systems had developed technologically, environmentally and in terms of financial, physical, social and human capital. Additionally, official statistics of the Cai Nuoc district for health and education were obtained from the district administration.

3. Results

3.1. Changing Land Use Patterns

Since 1968 land use patterns in the Cai Nuoc district have changed dramatically (Table 1). In 1968 rice monocropping with 1 rice crop year^{-1} covered more than half of the total land area of the Cai Nuoc district.

Mangrove forests covered 19,509.74 ha (or nearly 25% of the total district area) of the Western and Southern part of the district. Shrimp-based farming systems were non-existent. In 1992 rice monocropping with 1 rice crop year^{-1} was still the most prevalent land use pattern. The forest area had sharply decreased to 2.87% of the total district area, while mixed mangrove-shrimp farming systems covered nearly 10% of the Cai Nuoc district (Table 1, Fig. 2). Shrimp monoculture was still marginal. In the mangrove-shrimp farming systems, farmers grow mangrove (good for 50 to 70% of the total surface area covered by the system) and shrimp (*Penaeus monodon* Fabricius) simultaneously. In 1997/98, rice monoculture with two rice crops year^{-1} had become the major land use pattern, followed by rice systems with one rice crop year^{-1}. Together, both systems totalised slightly more than 60% of the total land area. A small strip of mangrove forest bordered the coastline. Behind this forest, an area of 7,639 ha of mangrove-shrimp farming systems was situated. Shrimp (*P. monodon*) monoculture systems developed along the Southern and Eastern part of the district's borders. In 1997, both shrimp systems together were good for 15.43% of the land. In 2003, shrimp monoculture systems covered 72.66% of the total land (Fig. 3). From the survey data it became clear that shrimp farming boomed in 2001. In 2002 and 2003, shrimp monoculture lost importance, while more diversified aquaculture systems that combine shrimp culture with rice, crab or fish gained importance.

3.2. Surface Water

The variables EC, salinity, Cl^-, SO_4^{2-}, COD and PO_4^{3-} showed significant seasonal effects (Table 2). The pH in the wet season 2003 was significantly lower than the pH in the wet season 2002. The EC, salinity and COD of the dry season 2004 were significantly higher ($p<0,001$) than their respective values in the dry season 2003, while the COD, NO_3^-, NH_4^+ and PO_4^{3-} of the wet season 2003 were significantly higher than their respective values in the wet season 2002.

3.3. Soil

The variables pH, $EC_{(1/5)}$, EC_e, Cl^-, soluble cations (Mg, Na, K), exchangeable cations (Na, K) showed significant seasonal effects (Table 3). The figures of these was significantly higher in the dry season compared to the wet season.

3.4. Socio-economic Changes

3.4.1. Loans

The survey revealed that 58.2% of the households in the Cai Nuoc district took a loan. Most of them (77.8%) took loans in 2000 or 2001 to invest in shrimp culture. Another 17.8% took loans in 2002 for the same reason. The mean loan is about 928 USD household^{-1}. Only 2 of the interviewed farmers had a loan that dated back to the years preceding 2000. 44.4% of all loans had to be paid back within a year.

3.4.2. Education

Fig.4 gives an overview of the official educational figures for the Cai Nuoc district. Between 2000 and 2002 the number of children in primary education dropped remarkably. At the lower and higher secondary levels, the number of students increased.

3.4.3. Health

Fig.5 gives an overview of selected official health figures for the Cai Nuoc district. Malaria and dengue fever showed a clear declining tendency from 1997 onwards: from 17 806 and 1803 infected persons, respectively, in 1997, to 1809 and 25 infected persons, respectively, in 2003. Dysentery increased: from 167 affected persons in 2001 to 1462 affected persons in 2002. The number of under-5 children with malnutrition was much higher in 2002 and 2003 (3910 and 5149, respectively) as compared to 1997 (1316 children).

3.4.4. Production Problems

Shrimp mortality is the major concern for the farmers in the district. It was a favourite and most emotional discussion subject during the field survey. 72.5% of the surveyed farmers acknowledged that they experienced higher shrimp mortality in 2003 than in 2002. Average shrimp survival rates for 2003 were 20% (Std. Dev. 18%, median 15%). 20.9% of the farmers had to live with a survival rate of 0%. Half of the farmers attributed high shrimp mortality to

the emergence of shrimp diseases. One fifth of the farmers was aware that the water conditions are declining. 27% of the farmers did not have any idea why shrimps die.

3.4.5. Shrimp Profitability

The average total investment costs for growing one crop of post-larvae to big adult shrimps was about 79 USD $crop^{-1}$ (Std. Dev. 57 USD), with a huge discrepancy between farms, from 1 to 267 USD $crop^{-1}$, largely depending on the amount of post-larvae farmers purchased. The average price paid for 1000 post-larvae was 2.43 USD. Post-larvae constituted the biggest investment costs for the farmers (72% of the total investment costs). The remainder was spent on inputs like feed, medicines and pond design.
Shrimps were harvested at different sizes: small, medium or big: 45, 35 and 25 shrimp kg^{-1} respectively. All the farmers indicated their desire to raise bigger shrimps. However, at the onset of disease problems, they are more likely to harvest even if the shrimps are small in size. 14.7% of the interviewed farmers were forced to harvest small shrimps, while 4.4% were able to harvest medium sized shrimps. Most farmers harvested a combination of mixed sizes: 15% could harvest small or medium shrimps, 44% could harvest at medium or big shrimp size, while only 3% could harvest crops of fully big shrimps.
The return on investment of small and medium sized shrimps was too low. The farmers got a net profit of -63, -35 and +8 USD $crop^{-1}$, for small, medium and large shrimps, respectively. Farmers harvesting small and medium shrimp only had a return of 20 and 55%, respectively, of their investment costs. Farmers who harvested big shrimps made a profit of 1.1% on their investments.

4. Discussion

4.1. Land Use Changes

4.1.1. Changes and their Drivers

Since 1968, land use patterns in the Cai Nuoc district have changed dramatically (Table 1; Figs. 2 & 3). These changes were mainly characterized by an intensification of the cropping system. The rice monocropping system with 1 rice crop $year^{-1}$ practised from 1968 to the 90's was followed by a rice monocropping system with 2 rice crops. At the onset of the new millennium, shrimp farming took over. Rice-based farming systems, which covered more than 50,000 ha between 1968 and 1997, had completely disappeared by the year 2003.
The drivers for these dramatic changes in land use are fairly well documented. At the national level, the Doi Moi liberalisation policy gave more opportunities to farmers [18]. As a result farm activities shifted to intensive and more diversified cultivation systems [19]. At the farmers' level, the swap in land use can be explained by the drive to get more food and/or income per unit land. In Thailand, the high farm gate price of shrimp relative to rice made farmers swap from rice monoculture to shrimp monoculture [20, 21]. Also in Vietnam, shrimp culture is very attractive because of its potential for high and quick returns on investments [9, 19].
The original land use plans drafted by the local government in 1997 clearly specified rice-fish farming systems and double rice cropping in the inland area. However, when farmers converted en masse to shrimp farming, the master plan was corrected [12]. This is a clear indication that the shrimp boom was primarily farmer-driven. This drive by farmers to cash in on high shrimp prices is not an isolated case. In the past decades, a massive transformation of coastlines in tropical developing economies has been observed [2, 7].

4.1.2. Deforestation

Between 1968 and 2003, the forest area declined drastically (Table 1; Fig. 2). The ratio "forested area/total land cover" declined from 0.243 in 1968 to 0.069 in 2003 [10]. These observations confirm the trends observed in other countries [22]. In the Cai Nuoc district rice farming is the main culprit for the loss in mangrove forest. Between 1968 and 1992, an estimated 63.2% of the original mangrove area was lost to rice culture (Fig. 2) [10]. From 1992 onwards, all losses in mangrove could be attributed to monoculture shrimp farming. While many farmers recognize that mangrove land is not suitable for shrimp aquaculture, it is still illegally converted to shrimp monoculture land [12]. It is well known that the inability to appreciate the economic importance of mangrove ecosystem services has been a major driving force in the conversion of mangrove into alternative uses such as shrimp ponds [23, 24].

4.2. Shrimp Farming

Farmers in the Cai Nuoc district can be classified as extensive shrimp farmers. Having limited resources, farmers mainly invest in the basic requirements such as hatchery-reared post-larvae. Little attention is paid to managerial and environmental issues. It is therefore not surprising that the output is extremely low. The shrimp yields in the Cai Nuoc district are lower that the 300 to 800 kg ha^{-1} $crop^{-1}$ range that is a characteristic of extensive systems [25-27]. In general, the shrimp yields in the Mekong Delta are known to be low: 200 kg/ha, by far the lowest figure amongst the major shrimp producing countries [26].

4.3. Surface Water

The EC, SO_4^{2-} and salinity data (Table 2) clearly show that salt has become a major problem in the Cai Nuoc area. In the dry season, salinity levels become extremely high, even higher than that of the oceans [28]. In the wet season levels remain high (> 8 g l^{-1}), clearly indicating that the wet season rains cannot flush out the accumulated salts. In April and May 2000 (transition between dry and wet season, before the shrimp boom), the average salinity in the rivers of Ca Mau province was 2.23 g l^{-1} [13], which shows that since the shrimp boom, the salinity in the surface waters has increased. It is indeed well known that shrimp culture often results in salinisation of the surrounding surface waters [21, 29].
Besides the salinisation process, our data (Table 2) clearly demonstrate that the COD levels show an increasing trend in both the wet and dry season, while PO_4^{3-}, NO_3^- and NH_4^+ levels all increase significantly in the wet season. Together with the fact that DO levels in rivers are on average 3.88 mg l^{-1} (Table 2), this clearly points towards increased organic pollution. Organic pollution and local hypernutrification and eutrophication in shrimp aquaculture are well known problems [21, 25, 30].

4.4. Soil

Data of salinity related variables showed an obvious threat of salinity to the soil environment. Soils in the Cai Nuoc area experienced a quite high salt concentration in the dry season (EC=5.23 mS/cm), and still quite a large amount of salts remained in the soil medium in the wet season (EC=3.85 mS/cm). The minimum soil salinity level even exceeded the threshold of saline soils (min EC_e=6.34 compared to EC_e=4 mS/cm) [31, 17]. In the wet season of 1998, soil salinity (expressed as EC) in the rice-shrimp system in the neighbouring Baclieu and Soctrang provinces was recorded at only 2.11 mS/cm and 1.40 mS/cm, respectively; and it was even much lower in the rice monocultute system (0.73 mS/cm and 0.58 mS/cm respectively) [32]. Comparisons of these data led to the conclusion that soil salinity levels has increased in the soil medium in recent years. The most likely cause of the increase was the shrimp farming, which experienced a very fast development in the area since the year 2000 [10].

4.5. Socio-economic Impact

The 2003 shrimp yields were bad. Farmers harvesting medium or small sized shrimps made huge losses. Besides, the amount of money loaned averages almost 933 USD $household^{-1}$, which is 10 times more than the income earned from one crop of big shrimps in 2003. At a rate of 2 crops $year^{-1}$, households need at least five years of two excellent crops of big shrimps $year^{-1}$ to pay back this debt. It is not amazing that many households in the Cai Nuoc district face serious financial problems. During the survey, many parents admitted that they could no longer pay the school fees for their children's education, which is clearly reflected in Fig. 4. In Thailand, the shrimp farming industry also brought about social displacement and marginalization [27].
The potential of shrimp aquaculture to improve the nutrition and incomes of the poor has been impeded by the emphasis on the cultivation of high value shrimps destined for export markets in Europe, USA and Japan [25, 27]. Our data reveals that the shrimp aquaculture industry did not bring a higher level of food security to the Cai Nuoc district (Fig. 5). When their production fails, farmers receive very little income to purchase rice, their main staple food. While the local markets might have enough rice, farmers with failed shrimp crops do not have enough money to purchase rice.

4.6. Sustainability?

The potential for high and quick returns on investments makes the shrimp aquaculture industry very attractive to farmers. However, productivity is very unstable and farmers are facing considerable financial risks in the event of a complete crop failure [9, 10]. Our 2003 data for the Cai Nuoc district showed that 20,9% of the farmers had experienced a total crop failure.
Several authors have demonstrated the environmental unsustainability of the shrimp monoculture industry. For Colombian semi-intensive shrimp farms the ecological footprint was 35-190 times the surface area of the farm [33]. In the Cai Nuoc district, the 1992 shrimp area to forest area ratio was 1:2.5. For 1997/98 and 2003 the ratios were 1:1

and 12:1, respectively [10]. From these figures, it is clear that the sustainability of the shrimp industry in the Cai Nuoc district cannot be guaranteed. The negative impact of shrimp farming on the local environment and on the socio-economic situation in the area, is therefore not surprising. Indeed, data from Indonesia and Vietnam show that shrimp productivity rapidly declines and that the risk of disease outbreaks increase after some years of operation [34, 35]. Failure to acknowledge the life-support function of mangroves is one explanation for the boom-and-bust pattern of shrimp aquaculture [36]. There are roughly 35,000 ha of abandoned shrimp ponds in the Mekong Delta of which about 50% may be rehabilitated [19]. In Thailand, 70% of previously productive ponds have been abandoned [37].
Shrimp monoculture in the Cai Nuoc district is creating a typical human ecological problem with regard to the relationship between the ecosystem and the socio-economic system: fast economic development in a non-sustainable manner purely for short-term economic gains. Within developing countries, coastal areas are often characterized by such conflicts between economic interests and environmental interests. The environment often has to pay the highest price. The result is too often a lose-lose situation, in which the economic gain is a short term, unsustainable gain. As a result, neither the environment nor the economic activities can survive [38].

4.7. Mitigation Measures

It is of utmost importance to be aware of the environmental consequences that have so often accompanied shrimp aquaculture. Practices that are environmentally non-degrading, technically appropriate, economically viable and socially acceptable should therefore be promoted.
The issues discussed in this paper clearly suggest that several problems experienced in the Cai Nuoc district should be urgently addressed, preferably by the government. Some of the socio-economic issues in the Cai Nuoc district that should be urgently addressed by the government are the increasing food insecurity and the deteriorating educational picture. Besides, integrated aquaculture management should be promoted. The government should organize courses focusing on good and appropriate farming practices, environmental degradation (related to shrimp farming) and protection. A balanced policy would include effective training and education, monitoring and enforcement of regulations and standards, rehabilitation of abandoned ponds, appropriate land use management, community involvement, and government reorganization to eliminate overlapping jurisdictions amongst the various agencies. It is under these conditions that the expectations for higher incomes and better access to socio-economic services (health and education) from shrimp culture can be realized.

Acknowledgements

The research has been made possible with financial assistance of the Flemish InterUniversity Council (VLIR), Belgium.

References

[1] Pingali, P., Hossain, M. and Gerpacio, R. 1997. Asian Rice Bowls: the Returning Crisis. CAB International, New York.
[2] Gujja, B. and Finger-Stich, A. 1996. What price prawn? Shrimp aquaculture's impact in Asia. Environment 38, 12-39.
[3] Chua, T.E. 1992. Coastal aquaculture development and the environment - the role of coastal area management. Marine Pollution Bulletin 25, 98-103.
[4] Funge-Smith, S.J. and Briggs, M.R.P. 1998. Nutrient budgets in intensive shrimp ponds: implications for sustainability. Aquaculture 164, 117-133.
[5] Thornton, C., Shanahan, M. and Williams, J. 2003. From Wetlands to Wastelands: Impacts of Shrimp Farming. Environmental Justice Foundation, London, UK.
[6] Primavera, J.H. 1991. Intensive prawn farming in the Philippines - ecological, social, and economic-implications. Ambio 20, 28-33.
[7] Dewalt, B.R., Vergne, P. and Hardin, M. 1996. Shrimp aquaculture development and the environment: people, mangroves and fisheries on the Gulf of Fonseca, Honduras. World Development 24, 1193-1208.
[8] Primavera, J.H. 1997. Socio-economic impacts of shrimp culture. Aquaculture Research 28, 815-827.
[9] Lebel, L., Tri, N.H., Saengnoree, A., Pasong, S., Buatama, U. and Thoa, L.K. 2002. Industrial transformation and shrimp aquaculture in Thailand and Vietnam: pathways to ecological, social, and economic sustainability? Ambio 31, 311-323.
[10] Binh, T.N.K.D., Vromant, N., Hung, N.T., Hens, L. and Boon, E.K. 2004. Land cover changes between 1968 and 2003 in Cai Nuoc, Ca Mau peninsula, Vietnam. Environm. Devel. Sustain. (submitted).
[11] Phuong Mai 2004. Ca Mau: rice-shrimp an mangrove-shrimp systems. Le Courier du Vietnam, 20-04-2004. (In french)
[12] Nhuong, T.V., Luu, L.T., Tu, T.Q., Tam, P.M. and Nguyet, T.T.A. 2002. Viet Nam Shrimp Farming Review, Individual Partner Report for the Project, Policy Research for Sustainable Shrimp Farming in Asia. European Commission INCO-DEV Project PORESSFA No. IC4-200110042, CEMARE University of Portsmouth UK and RIA, Bac Ninh, Viet Nam.
[13] Sub-Institute of Geography at Ho Chi Minh City 2001. Studying the Scientific Basis for the Planning Adjustment, Production Rearrangement at Cai Nuoc district, Ca Mau province (2000 – 2001). Sub-Institute of Geography at Ho Chi Minh City, Ho Chi Minh City.

[14] Brennan, D., Clayton, H., Be, T.T. and Hiep, T.T.N. 1999. Economic and Social Characteristics and Farm Management Practices of Farms in the Brackish Water Region of Soc Trang and Bac Lieu provinces, Mekong Delta, Vietnam, Results of a 1997 Survey. (http://www.reap.com.au/riceshrimpsurvey97.pdf)
[15] Ministry of Science, Technology and Environment 1995. Vietnamese Standards on Environment. Volume 1. Ministry of Science, Technology and Environment, Hanoi, Vietnam. (In Vietnamese)
[16] Chieu, T.T. and L.T. Bat, 1999. Handbook for Soil Investigation, Assessement and Classification. Agricultural Publishing House. (In Vietnamese), pp 14-73.
[17] Rowell, D.L., 1994. Soil Science: Methods and Applications. Department of Soil Science, University of Reading, pp. 153 – 163, 287 – 289.
[18] The government resolution 09/NQ-CP, 2000 allowed farmers to transform coastal saline rice fields into shrimp farms, while the 'National Master Plan for Aquaculture' encouraged the development of the shrimp farming industry. Also the Ca Mau provincial coastal aquaculture plan for the period 2000-2010 demanded an expansion in shrimp farm area and an intensification of shrimp aquaculture, mainly along the coast.
[19] Sanh, N.V., Xuan, V.T. and Phong, T.A. 1998. History and Future of Farming Systems in the Mekong Delta. In: Development of farming systems in the Mekong Delta of Vietnam. Xuan, V.T. and Matsui, S. (eds.). JIRCAS, CTU & CLRRI, Ho Chi Minh City, pp. 16-80.
[20] Braaten, R.O. and Flaherty, M. 2000. Hydrology of inland brackishwater shrimp ponds in Chachoengsao, Thailand. Aquacultural Engineering 23, 295-313.
[21] Flaherty, M., Vandergeest, P. and Miller, P. 1999. Rice paddy or shrimp pond: tough decisions in rural Thailand. World Development 27, 2045-2060.
[22] NACA 2002. Shrimp farming and the environment. Can shrimp farming be undertaken sustainably? NACA, Bangkok.
[23] Barbier, E.B. 1994. Valuing environmental functions: tropical wetlands. Land economics 70, 155-173.
[24] Rönnbäck, P. 1999. The ecological basis for the economic value of mangrove forests in seafood production. Ecological Economics 29, 235-252.
[25] Primavera, J.H. 1998. Tropical shrimp farming and its sustainability. In: Tropical Mariculture. de Silva, S. (Ed.). Academic Press, New York, pp. 257-289.
[26] Rosenberry, B. 1999. World shrimp farming, 1999. Shrimp News International, San Diego.
[27] Rönnbäck, P. 2001. Shrimp Aquaculture: State of the Art. Swedish EIA Centre, Report 1. Swedish University of Agricultural Sciences (SLU), Uppsala.
[28] Tho, N., Vromant, N., Hung, N.T. and Hens, L. 2005. Organic pollution and salt intrusion in Cai Nuoc district, Ca Mau province, Vietnam. Water Environment Research, Accepted.
[29] Braaten, R.O. and Flaherty, M. 2001. Salt balances of inland shrimp ponds in Thailand: implications for land and water salinization. Environmental Conservation 28, 357-367.
[30] Latt, U.W. 2002. Shrimp pond waste management. Aquaculture Asia 7, 11-16.
[31] Tan, K.H., 1993. Principles of Soil Chemistry, 2nd edition. Department of Agronomy, the University of Georgia, Athens, Georgia, pp. 260 – 273.
[32] Preston, N. and Clayton, H. (Eds), 2003. Rice-shrimp farming in the Mekong Delta: biophysical and socioeconomic issues. ACIAR Technical Reports No.52e, 170p).
[33] Larsson, J., Folke, C and Kautsky, N. 1994. Ecological limitations and appropriations of ecosystem support by shrimp farming in Colombia. Environmental Management 18, 663-676.
[34] Dierberg, F.E. and Kiattisimkul, W. 1996. Issues, impacts, and implications of shrimp aquaculture in Thailand. Environmental Management 20, 649-666.
[35] Be, N.V. 2000. An Evaluation of Coastal Forest and Fishery Resources Management Strategies in Camau and Bentre Provinces in the Mekong Delta, Vietnam. PhD. Thesis, University of Philippines, Los Baños.
[36] Moberg, F. and Rönnbäck, P. 2003. Ecosystem services of the tropical seascape: interactions, substitutions and restoration. Ocean & Coastal Management 46, 27-46.
[37] Stevenson, N.J. 1995. Disused shrimp ponds: options for redevelopment of mangroves. Coastal management 25, 425-435.
[38] Costa-Pierce, B.A. 2000. Aquaculture ecosystem. In Responsible Aquaculture in the New Millennium. Flos, R. and Creswell, L. (eds.). Special Publication no. 28. European Aquaculture Society, Oostende, Belgium.

Table 1. Major land use categories (%) in the Cai Nuoc district for the years 1968, 1992, 1997 and 2003.

Land cover	1968	1992	1997	2003
1 rice crop year^{-1}	54.16	43.07	26.08	0.00
2 rice crops year^{-1}	0.00	0.00	34.59	0.00
Settlement & gardens	8.30	23.76	20.30	18.69
Mangrove forest & Nypa	23.15	2.87	2.15	2.07
Mangrove-shrimp	0.00	9.93	9.30	6.21
Shrimp farming	0.00	0.42	6.13	72.66
Other	13.29	20.35	2.45	0.37

Table 2. Changes in surface water over 4 seasons (2002-2004) in Cai Nuoc district, Ca Mau Province, Vietnam.

				ANCOVA				Means comparison		Means comparison			
Var.	Unit	Mean	Std. Dev.	Time	Water	Time * Water	Distance	Canal	Shrimp	Wet 2002	Dry 2003	Wet 2003	Dry 2004
pH		7.68	0.45	*	***	ns	ns	7.44^{a}	7.83^{b}	7.75^{b}	7.69^{b}	7.45^{a}	7.64^{ab}
EC	mS cm^{-1}	40.2	28.3	***	ns	***	**	39.3^{a}	40.8^{a}	14.6^{a}	62.6^{b}	13.1^{a}	70.0^{c}
Salinity	g l^{-1}	25.75	18.14	***	ns	***	**	25.17^{a}	26.14^{a}	9.38^{a}	40.04^{b}	8.41^{a}	44.78^{c}
Cl^{-}	g l^{-1}	13.72	9.73	***	ns	***	*	13.34^{a}	13.98^{a}	4.98^{a}	22.0^{b}	4.45^{a}	23.2^{b}
SO_4^{2-}	mg l^{-1}	1988.1	1380.0	***	ns	***	***	1976.0^{a}	1996.2^{a}	753.1^{a}	3066.1^{b}	670.8^{a}	3455.6^{c}
DO	mg l^{-1}	6.03	2.87	ns	***	ns	ns	3.88^{a}	7.45^{b}	5.10^{a}	6.32^{a}	5.14^{a}	6.12^{a}
COD	mg l^{-1}	215.2	165.4	***	ns	*	ns	222.6^{a}	210.2^{a}	43.9^{a}	273.2^{c}	127.2^{b}	421.4^{d}
NO_3^{-}	mg l^{-1}	0.115	0.072	***	**	ns	ns	0.094^{a}	0.130^{b}	0.083^{a}	0.119^{ab}	0.150^{b}	0.096^{a}
NH_4^{+}	mg l^{-1}	0.030	0.032	*	ns	ns	ns	0.027^{a}	0.031^{a}	0.011^{a}	0.032^{bc}	0.049^{c}	0.024^{ab}
PO_4^{3-}	mg l^{-1}	0.108	0.127	***	**	***	ns	0.145^{b}	0.082^{a}	0.115^{b}	0.095^{ab}	0.209^{c}	0.036^{a}

Table 3. ANOVA testing of the soil variables in the Cai Nuoc district. ANOVA significance level: ns (not significant), * (p<0.05), ** (p<0.01), * (p<0.001). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level.**

Variable	Unit	Significance testing	Mean's comparisons	
		Season	Wet season	Dry season
$pH_{(1/2.5)}$	-	**	6.38^{a}	6.71^{b}
$EC_{(1/5)}$	$mS.cm^{-1}$	***	3.85^{a}	5.23^{b}
EC_e	$mS.cm^{-1}$	***	24.65^{a}	33.44^{b}
Cl^{-}	$mg.100g^{-1}$	***	516.93^{a}	851.86^{b}
SO_4^{2-}	$mg.100g^{-1}$	ns	351.72^{a}	303.06^{a}
Sol. Ca	$mg.100g^{-1}$	ns	34.73^{a}	44.76^{a}
Sol.Mg	$mg.100g^{-1}$	**	43.69^{a}	69.46^{b}
Sol. Na	$mg.100g^{-1}$	***	338.95^{a}	507.33^{b}
Sol. K	$mg.100g^{-1}$	***	22.62^{a}	32.64^{b}
Exc. Ca	$meq.100g^{-1}$	ns	11.78^{a}	12.70^{a}
Exc. Mg	$meq.100g^{-1}$	ns	16.43^{a}	16.61^{a}
Exc. Na	$meq.100g^{-1}$	***	16.19^{a}	22.82^{b}
Exc. K	$meq.100g^{-1}$	**	1.60^{a}	1.98^{b}

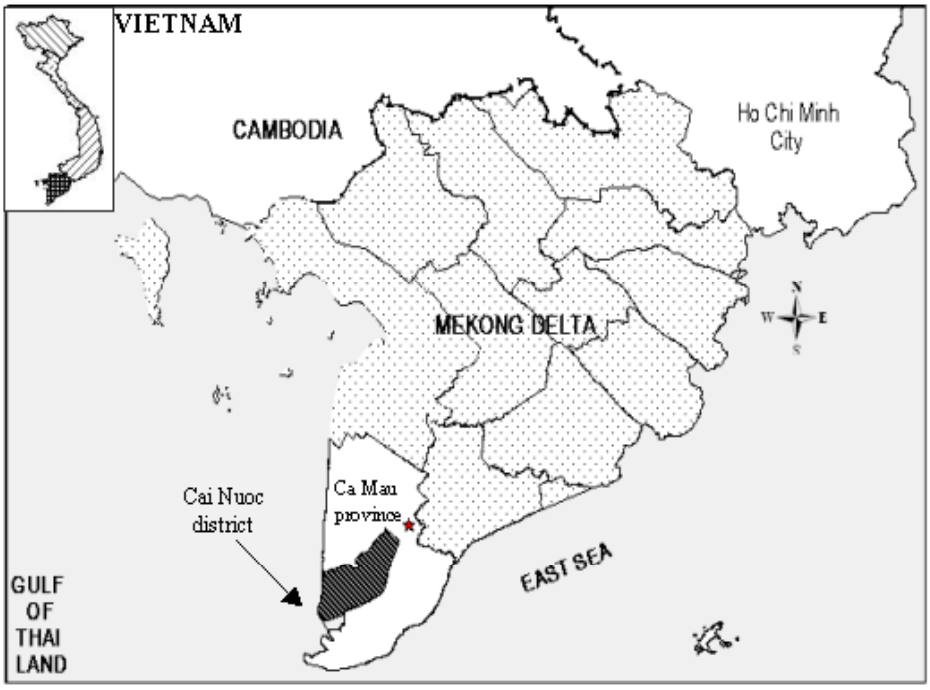

Fig. 1. Location of the Cai Nuoc district, Camau province, South Vietnam.

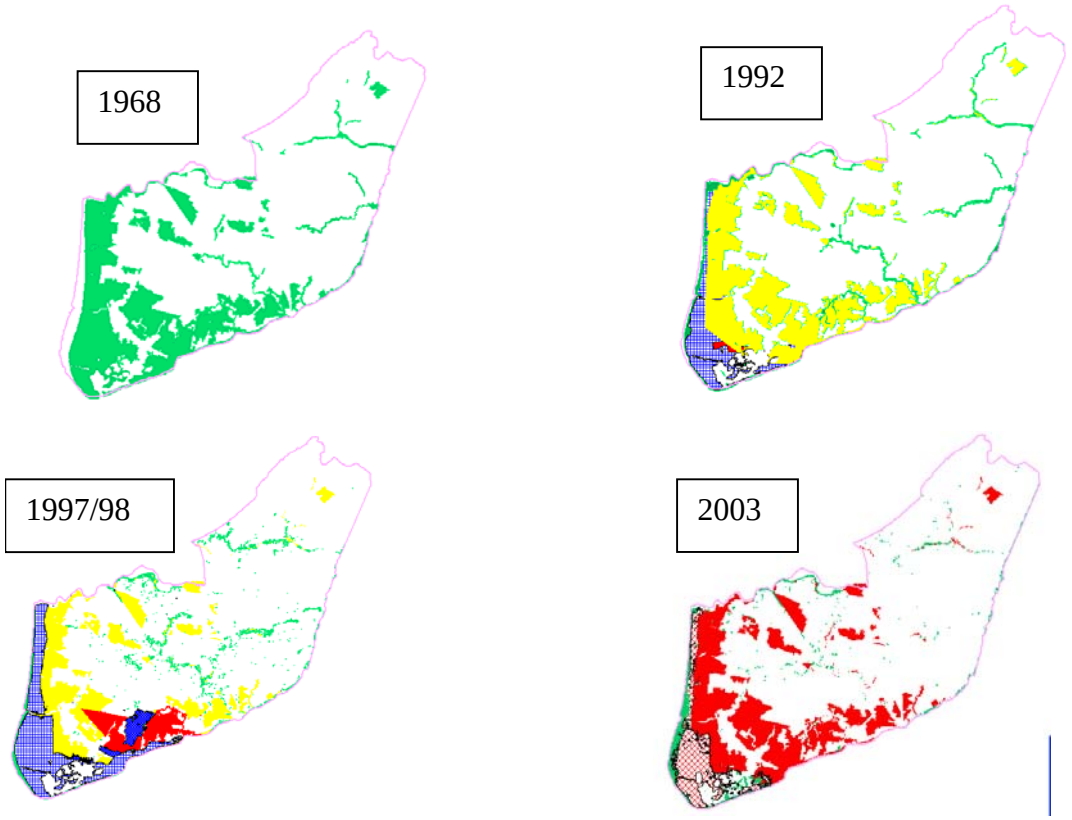

Fig. 2. Map showing the reduction in mangrove and Nypa stands. In 1968 about 25% of the area was covered by forest (green colour). By 1992, most of the forest had disappeared, mainly due to rice cultivation in the inland (yellow colour) and integrated mangrove-shrimp systems (purple) along the coast. By 2003, all land is covered by shrimp monoculture (red colour).

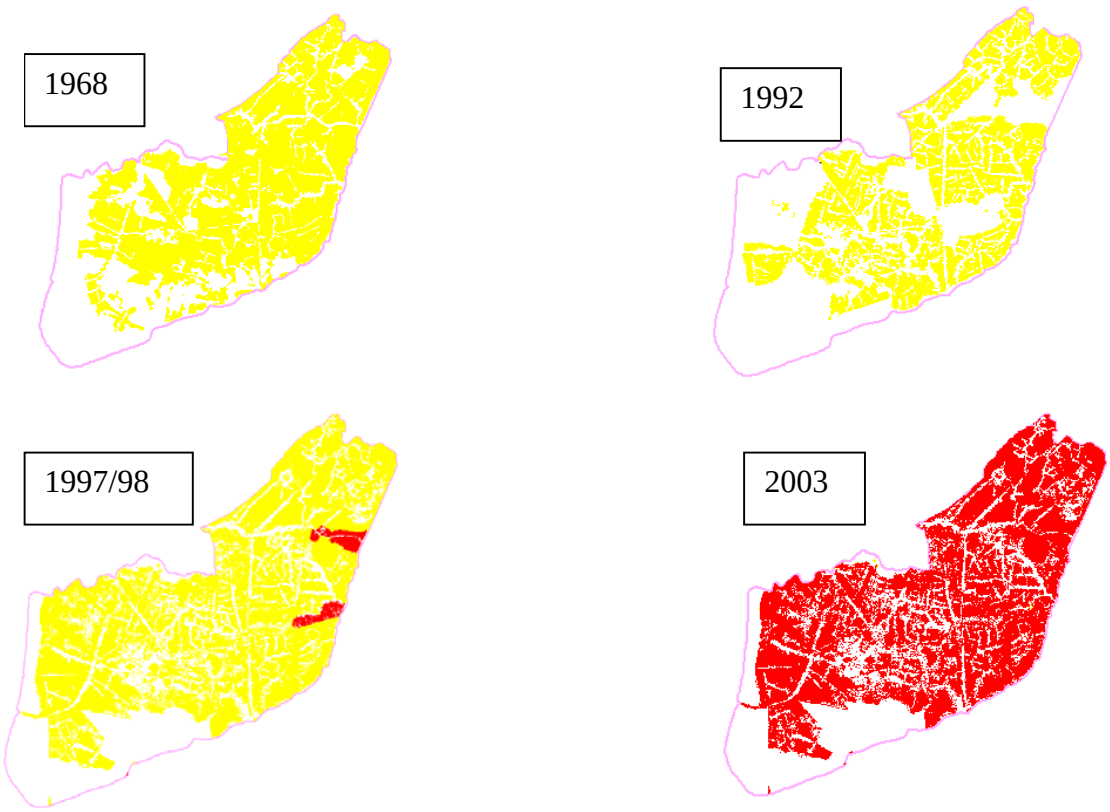

Fig. 3. Map showing the evolution from rice based farming systems (yellow colour) to shrimp monoculture farming (red colour).

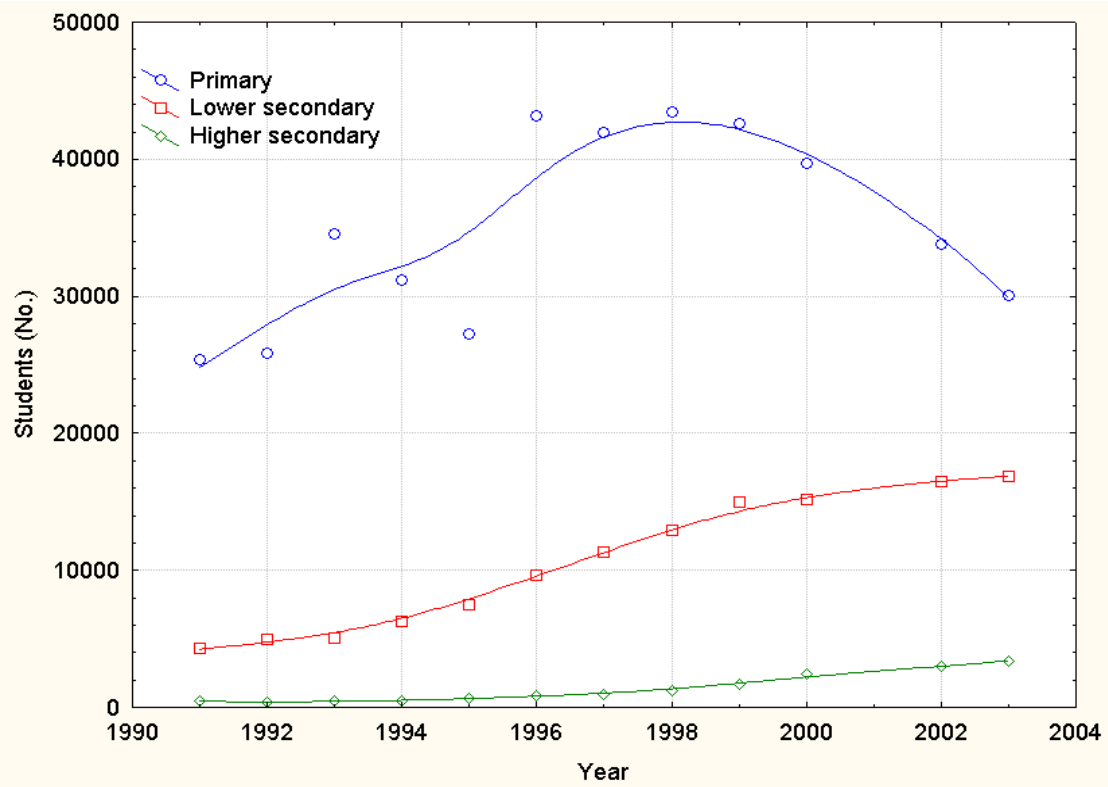

Fig. 4. Educational figures (number of students) for the Cai Nuoc district between 1991 and 2003. Source: Statistics Bureau of Ca Mau province and Statistic Department of Cai Nuoc district.

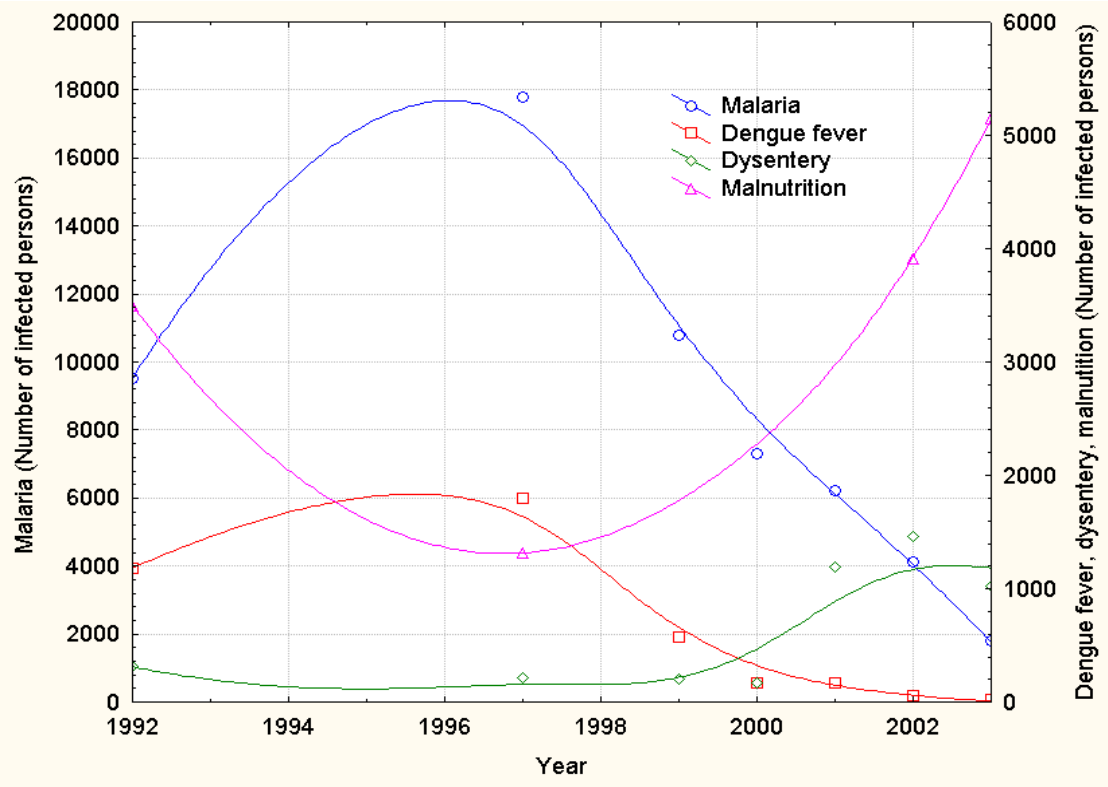

Fig. 5. Health figures (number of patients) for the Cai Nuoc district between 1992 and 2003.