GIS in support to data analysis for enhanced sustainability of shrimp farming in the Mekong Delta, Vietnam

Jacques Populus (1), Raweewan Nutpramoon (2), Jean-Louis Martin (3), Pascal Raux (4)
Yves Auda (5), Hoang Son (6)

(1) Ifremer, DEL/AO, Centre de Brest, Plouzané (FR)
(2) GISTDA, Bangkok (TH)
(3) Crema (FR)
(4) CEDEM-UBO, Brest (FR)
(5) CESBIO, Toulouse (FR)
(6) Institute of Oceanography, Nha Trang (VN)

Abstract

Over the last twenty years, extensive shrimp aquaculture has dramatically expanded in the coastal fringe of the Mekong Delta. This occurred primarily at the expense of the mangrove, already severely affected by the Vietnam war. More recently, paddy land has been reclaimed for shrimp aquaculture, a higher currency earner. However, production collapses have frequently occurred and the overall yield has remained far below the expectations for traditional farming. A number of parameters enter into play in the success of this activity, summarized in two questions: i) is the Mekong deltaïc environment - under high continental pressure - suitable to shrimp farming, ii) if not, is it possible to adapt the low technicity of rural poor farmers to reach economic sustainability?

This paper is based on the analysis of two full sets of data. Ecological data are composed of hydrobiological, hydrodynamical and land cover data. The former were collected at a number of stations encompassing the local variability, the latter were derived from processing Spot imagery. Surveys of farms zootechniques and management were conducted over a network of shrimp farms, with the objective of determining the part played by these data in farming efficiency, with respect to the environmental conditions. Statistical methods, i.e. PCA for continuous variables and MCA (Multiple Correspondance Analysis) for qualitative ones respectively provided a zonation of the stations and a classification of the farms. GIS illustrated the distribution of the latter within the former. Summarizing yields per ecological zone revealed a production pattern that might lead to review present land use planning policy and in particular the widespread "integrated mangrove-shrimp" system.

1. Introduction

Shrimp Aquaculture in the Mekong Delta

Over the last twenty years, shrimp aquaculture has been developing rapidly in Asian region and particularly in Vietnam. Rapid expansion has resulted in high production, currently ranking this country seventh in total global shrimp production (Kautsky et al., 2000). The Mekong Delta is Vietnam's largest potential area for shrimp aquaculture, with a total production amounting to 49000 Mtons in 1997 (Johnston et al., 2000; Phuong and Hai, 1998). Shrimp yields vary among the various culture systems from widespread pure extensive farms tomore "semi-intensive" farms, respectively producing from 100-400 kg.ha-1.year-1 to 1000-2000 kg.ha-1.year-1 (Binh and Lin, 1995). The dominant shrimp farming system is the extensive one which relies on tidal recruitment of wild seed with additional stocking of hatchery-reared postlarvae at low densities with minimum feed supply. This means that shrimp growth is mainly supported by primary production via the food web. Water exchange is usually made by gravity during spring tides (Binh and Lin, 1995). Although shrimp farming has a positive impact for people in coastal areas in creating job opportunities and increasing foreign income, uncontrolled and rapid expansion has contributed to many problems: mangrove destruction, environmental degradation (Binh et al,. 1995, Graaf and Xuan, 1998), uncertain yield and low efficiency. As a reaction to yield decrease between 1990 and 1996 from 402 kg.ha- 1.year-1 to 268 kg.ha-1.year-1 respectively (Fuchs et al, 1998), attempts by farmers to increase the level of intensification from extensive to extensive plus and even semi-intensive systems have led to many collapses.

The notion of sustainability

The concept of sustainability ought to incorporate social, financial and ecological concerns (Roberts et al., 1995; Beveridge et al., 1997; Chamberlain, G.W., 1997). Sustainability depends primarily on the profits made by local households. In turn these profits do not depend on the level of intensity, but rather on the suitability of the technology, the quality of the practise with respect to the various assets the activity depends on, e.g. water as a common, but also soils and the vegetation, and more broadly the environment. There is an implicit relationship between aquaculture and its surrounding environment because aquaculture relies on a wide range of natural resources. Site selection is the first important criterion for sustainable aquaculture and can be guided or encouraged by government through wise planning, incentives, education and information.

Several studies have been carried out in the Mekong delta in order to improve shrimp aquaculture or investigate the main factors affecting its efficiency (Johnston et al., 2000, Minh et al., 2001). Their focus was mostly on zootechnics and socio-economics, through census and interviews currently undertaken by local bodies. For reasons of costs, none have so far embarked on probing the environment on a large scale to obtain a good picture of its carrying capacity.

The present EU-funded GAMBAS project (Global Assessment of Mekong Brackishwater Aquaculture of Shrimp) is being carried out jointly by Vietnamese and French institutes under the leadership of Ifremer. Its overall objective is to promote the sustainable development of shrimp brackishwater aquaculture in the Mekong delta by providing recommendations on how to avoid ecosystem degradation and further production collapses. It aims at assessing the status of shrimp aquaculture status based on ecological, zootechnical and socio-economic (figure 1) aspects in two study areas, by confirming on a significant sample of stations the reliability of quantifiable relationships between shrimp yield and ecological indicators., Its mapping component was deemed very important to present the information geographically as a tool supporting planning and management.

Figure 1: Main factors affecting shrimp production in extensive systems

2. Study sites and data collection

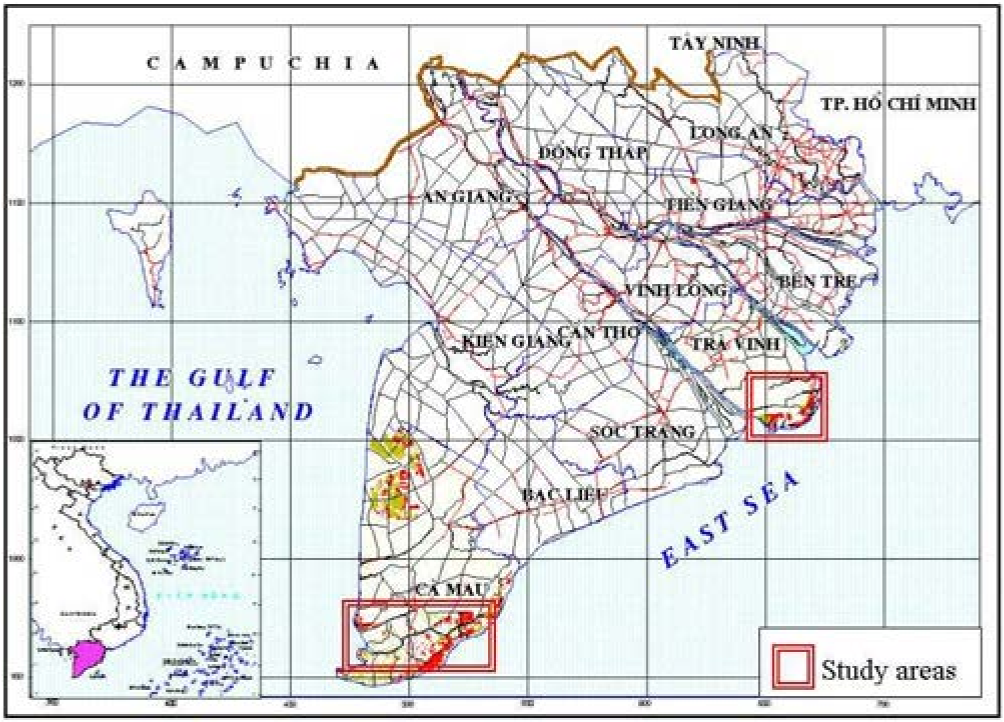

Figure 2 : Location of the study areas in the Mekong delta

The study sites are the TraVinh and Camau provinces (figure 2). Their climate is tropical with two monsoons, the dry north-easterly (December-April) and the rainy south-westerly (May-November). The two sites are transected by major rivers that carry most of the water and further stem into smaller rivers and canals. The Tra Vinh peninsula, lying between the Mekong river main two distributaries, the Co Chien and Hau Giang rivers, is under very high freshwater influence. The Camau peninsula is under prevailing marine influence, surrounded to the East by the South China Sea and to the West by the Gulf of Thailand, with respectively a semi-diurnal tide with an amplitude of 3-3.5 m and a diurnal tide with an amplitude of 1.1-1.5 metre. Unlike Tra Vinh where typical salinity drop from 25ppt in the dry season to about 5ppt in the rainy one, the rainy season has been shown to hardly influence at all flows and salinities in Camau waterways (Nguyen, 2002).

Figure 3 : the "integrated shrimp-mangrove" in the Camau province.

Mangroves are a key component of these sites, being either natural or replanted within or in the vicinity of shrimp ponds (figure 3). Their role as an organic matter sink and a habitat for many coastal species is well known (Tong et al., 2003). After being defoliated to a large extent during the Vietnam war, they have been steadily eradicated over the last twenty years under heavy and uncontrolled conversion into shrimp ponds (Thu, 2003, submitted). Figure 4 shows the rate of conversion in the Tra Vinh province over the last 40 years. Throughout the last decade, decrees on reforestation boosted the so-called "integrated shrimp-forest system", where mangrove trees gow on levees within the ponds (figure 3), but the value of this type of design to tree ecology seems questionable (Johnston et al., 2000).

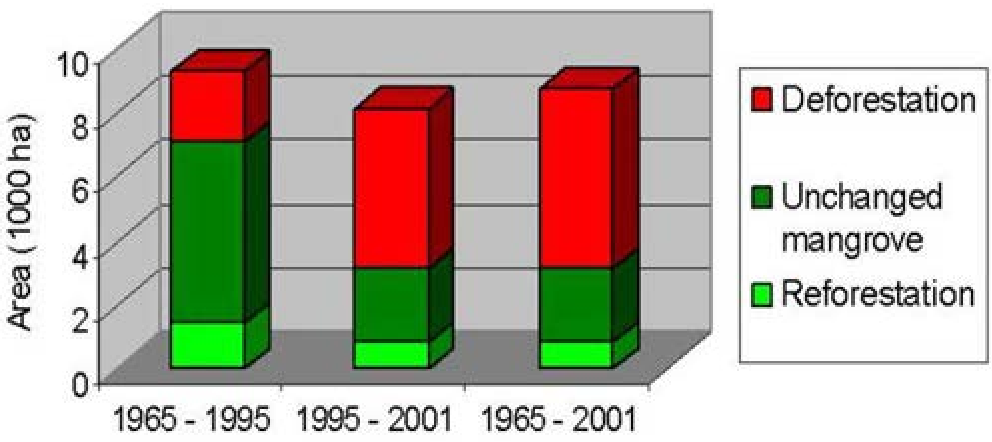

Figure 4: mangroves changes over 1965-2001, Travinh province (after Thu, 2003).

Hydrobiological data

Four surveys were carried out over the period 2001/2002 to cover the rainy and dry seasons. Water parameters were measured at 35 stations, which were chosen to cover the largest variability in terms of water ecology. Water samples were collected around high tide, corresponding to the usual period for water renewal to shrimp ponds. There were 21 parameters analysed with a view a) to acquiring an in-depth knowledge of the sites, b) and also to providing back up information allowing cross-checks and data quality assessment. These variables can be seen on the PCA results in figure 6.

In addition to hydrobiological measurements, a "confinement index" (CI) was designed as an indicator reflecting the rate of water renewal and turbulence within waterways and channels. Turbulence induces higher turbidity, which affects primary production in a negative way. For each station, the index was computed as the ratio of the distance from the station to the sea over the squared root of the canal cross section. The distance to the sea was the "hydrological" distance obtained by following the major discharge waterway. It was easily measured on a Spot satellite image. River cross section was simply measured with an ordinary hand held sounder. To assess the suitability of the index on both sites, a comparison was achieved with hydrodynamic computations carried out on the Camau site (Nguyen, 2002). By using a network of tide stations and river cross-sections over the area, a hydrodynamic code was run to compute maximum instantaneous and residual flows. A good correlation was found between maximum flow (itself reflecting turbulence) and CI.

Farming practice data

A sample of five shrimp farms was randomly selected in the vicinity of each station. The survey were performed in August 2002 using a questionnaire to interview 160 farmers. The questionnaire had many overlapping questions allowing to infer farm yields, an information some farmers were not willing to give. Some data concerned farm structure (e.g. pond area, age, number of sluices), others zootechnics or crop management (e.g. yield, stocking density, feed, pond depth etc...), others socio-economic aspects (e.g. labour, costs, training).

Geographic information and satellite imagery

General baseline information already existed in the form of land use maps produced by various initiatives, chiefly in Camau, which is currently a region of high concern to the government. These maps tended to be obsolete, given the rate of change underway there. Recent Spot imagery was therefore acquired with several purposes: a) get a more precise account of the actual river network and provide a reliable measure of the above mentioned "hydraulic" distance to sea, b) update the land use map. Classifications were conducted with a view to understand the relation between mangrove and shrimp farming yields, as the distribution of forest seemed to play a key role. Two colour Spot4 scenes in pseudo 10 metre resolution were acquired, on 10 April 2001 for Ca Mau and 22 January 2001 for Tra Vinh. All of these data were stored in a GIS.

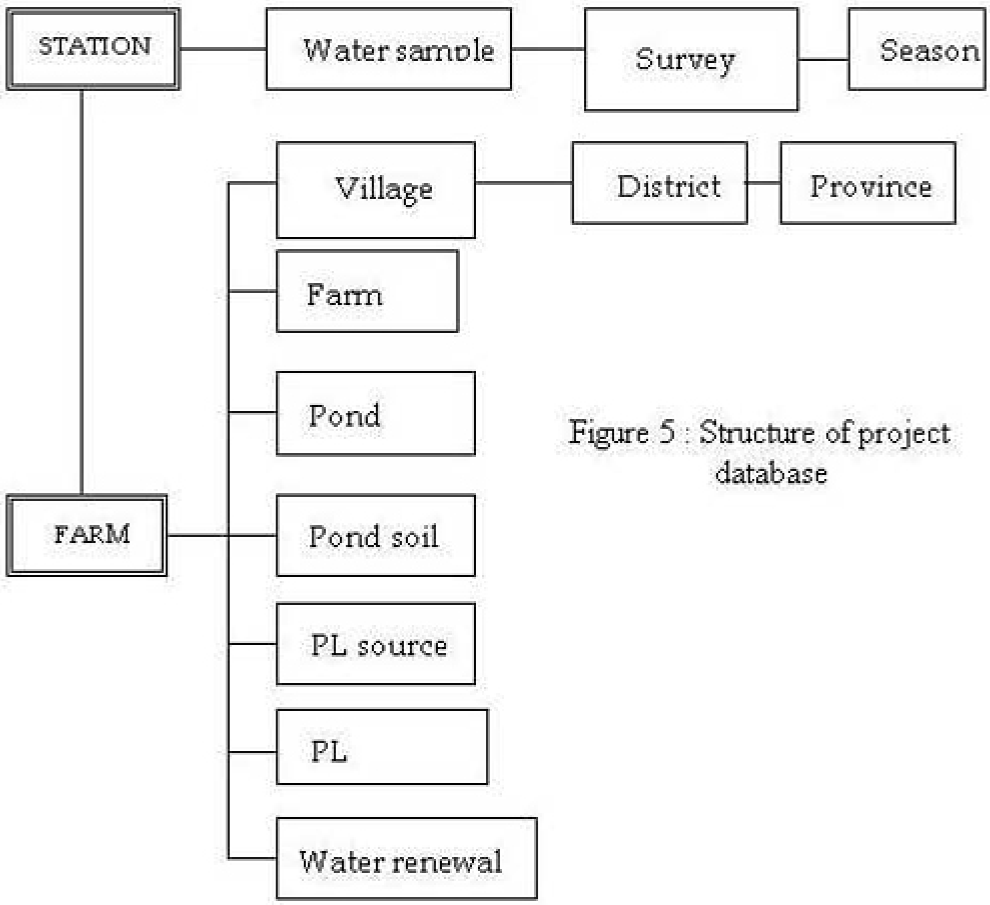

Figure 5 : Structure of project database

3. Statistical methods and tools

The methodology was divided into four main parts :
- build up a database for storing data from each activity of GAMBAS project (figure 5),
- perform multivariate analysis (PCA) on hydrobiological data (water quality),
- perform land ecology classification of satellite imagery,
- perform multiple correspondance analysis (MCA) on farm practise and performance data
- produce GIS maps at each step to illustrate patterns and results.

Hydrobiological zonation

The aim of the water quality classification was to try and understand how the hydrological parameters interact and also group together stations with similar environmental conditions. Considering that rainy season crops suffered from many collapses due to worse hydrobiological conditions, only dry season water quality data were selected for classification. Among the 21 water quality variables collected (physical, chemical and biological parameters), many were correlated, which allowed to cross-check them and hence get rid of corrupt measurements. Principal component analysis (PCA) allowed to reduce data dimension to a set of decorrelated variables giving a sufficient description of the aquatic environment. This reduced set will be later assessed as a potential monitoring set.

Ecological zonation

In terms of land ecology, pixel-based classifications proved worthless in such a composite environment, as appears on the Spot image in figure 8. Any given expanse of traditional aquaculture territory is composed of a variety of land sub-units such as water, bare soil, canals, households, (mangrove either randomly present or grown on levees typically less than 10 metres wide), shrubby vegetation etc... Only a global perception is possible, that mostly results from man-made transformations of the environment. For instance, areas where paddy has been converted to shrimp ponds exhibit little vegetation (limited to crop trees on the banks), whereas in mixed shrimp-mangrove systems, a very "mottled" texture appears. Therefore, only broad zonation was possible in terms of land use mapping. As a way to quantify the amount of total vegetation standing in the vicinity of each station, a classical vegetation index was also computed and averaged in a 1 km radius window.

Classification of shrimp farms

The data from the 160 farms were processed with multivariate analysis (Spad-n software). Two approaches were possible: a) to analyse directly all the data through multivariate analysis in order to get a farm typology and illustrate the discriminating factors among farms: respective weights of the environment, of practices, etc... b) for or a given environment, i.e for each hydrobiological zone, to study farms performances in view of their dominant zootechnical and socio-economics features. The stepwise way of the latter sometimes leads to reduced farm samples, hence limiting the confidence in the results. The first analysis was run on zootechnical and socio-economic variables only, to provide a farm typology. The second method was applied to the hydrobiological zones. Prior to these computations, data preparation implied very heavy work in cheking all surveyed data and recoding all variables into ordinal ones (usually in five modes).

Database update and map production

Water quality stations and shrimp farms were labelled according to the classifications and stored in an Access database (Figure 5). Maps were produced to present the results at different stages of data analysis. The difficulty was the type of data being handled, i.e. geographic objects as points (farms and stations). Stations being scattered along waterways, the only way to map stations into zones was by resorting to "buffers" of stations as polygons. A colour was attributed to each polygon, which, although not fully in line with graphic semiology principles, gave enough visual weight to each zone. Likewise, clusters of 5 farms located in close vicinity could not be easily mapped at medium scale. We had to resort to bar diagrams, each bar representing one farm and its module the desired variable.

4. Results and Discussion

Ecological zonation

The combination of satellite analysis and field surveys did not make it possible to find out field indicators which could provide immediate information on most suitable sites for shrimp aquaculture. Several land use units were discriminated and their peculiarities in terms of vegetation communities and determining broad ecological parameters, were stressed. The land-use chart is simplified, because human impacts are noticeable everywhere and this permanent disturbance of spontaneous ecosystems and changes in agricultural practices make difficult the production of a detailed map which could remain valid several years. The only way to produce a meaningful legend is to consider only large classes of land-use such as "mangroves", "aquaculture", "paddy field", etc. (Figure 6). Even with such a coarse classification, it is difficult to ascertain the reliability of the map at local levels.

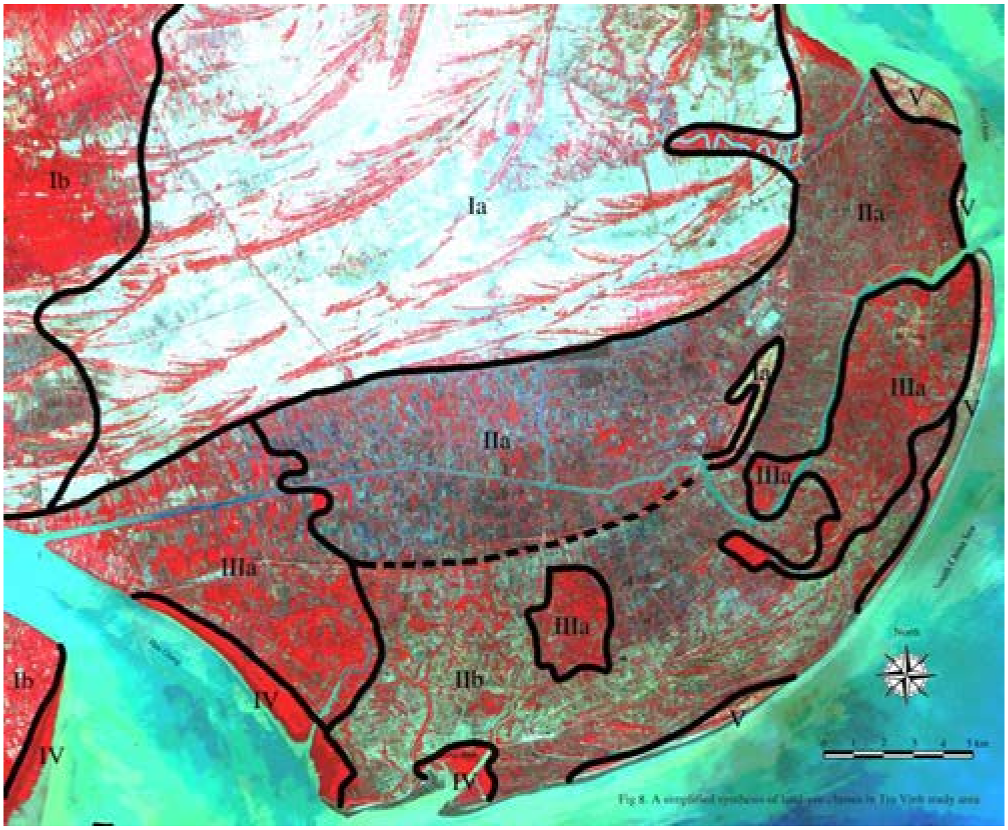

Figure 6 : global ecological zonation of the January 22, 2001 Spot 4 image, Tra Vinh site

Zone Ia and Ib are paddy areas not yet affected by aquaculture. In zone II, priority is given to shrimp ponds. All red patches on the image belong to mangroves. Ponds are under water almost all year around with the exception of short periods during which they are cleaned. All natural mangroves are reduced to degraded remnants along the waterways and very often ponds are deprived of any mangrove tree or brush. The flora of these mangroves is reduced to a few species including Nypa, Sonneratia caseolaris et Avicennia officinalis. The reduced number of mangrove species could be due to the magnitude of human impacts and water salinity levels usually lower than 15g/l, even if slightly higher values are recorded (15 to 20g/l) during very dry periods. In zone IIb, the landscape seems very peculiar: the commonest land-use units are salt pans, in which small dikes separating salt pans are extremely narrow (<50 m). They do not appear on satellite image, giving the impression of broad non partitioned territories. The resulting reflectance on the color composite is a light grey, indicating either terrains flooded by shallow waters or flood-free soils. What is observed from space is often the color of the salt pans bottoms.

In zone III, it seems established that the decision has been taken at governmental levels to maintain the acreage under mangroves at least at 50% of the total land-use. This ratio appears on satellite products. We are in this zone III in the mode called "mangrove sylviculture - shrimp farming" (mixed shrimp-mangrove forestry farms). Shrimp farming is mainly extensive or improved extensive ; it is found everywhere. All mangroves are secondary or artificial (planted). In both zones II and III, tidal fluxes are moving freely in main and secondary canals

The computation of the vegetation index (NDVI), a combination of the red and infrared channels computed in a 1 km radius circle around each station yielded a rough estimate of the amount of mangrove. Figure 7 is a graph of yield versus percentage of mangrove coverage. It shows that the presence of mangrove seems adverse to shrimp yield. This is probably true in the mixed system referred to above, where trees inside ponds are likely to generate a number of drawbacks to shrimp thriving (Jonhston, 2000): reduced water surface, tanins, litter, shadow.

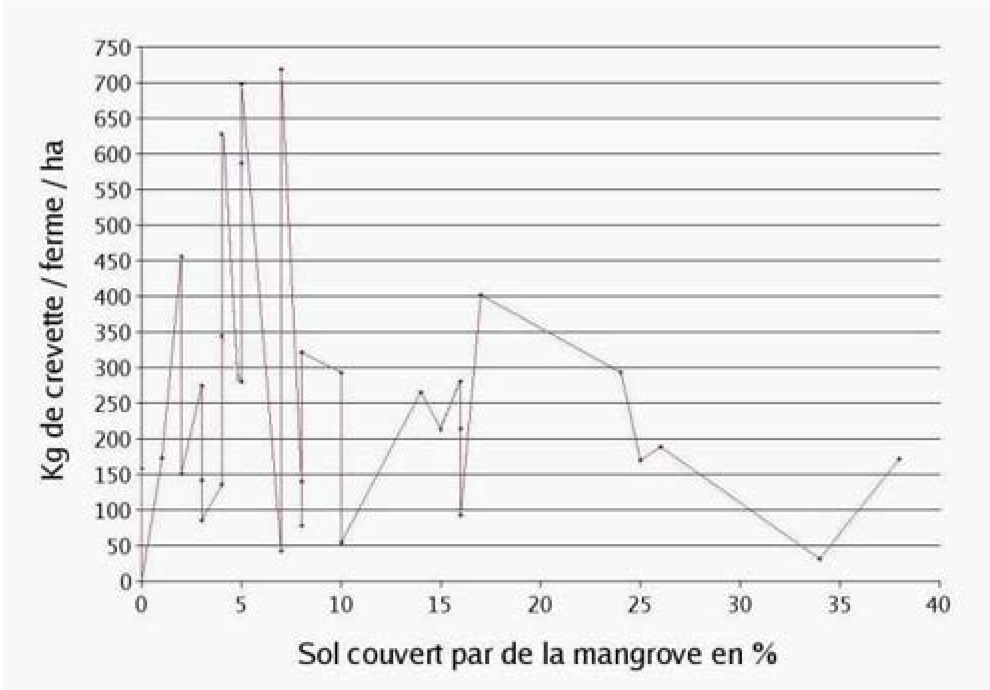

Figure 7 : shrimp yield versus amount of mangrove on study sites

Hydrobiological zonation

Figure 8 shows the plot of the first two components of the PCA. On component 1, there are strong correlations between variables related to particulate matter: turbidity, total suspended solids (TSS), Organic Matter, Nitrogen particulate, Carbon particulate and Nitrate (NO3). Salinity and pH are correlated with each other and discorrelated to the particulate group, which shows the alkaline "buffering effect" of seawater with respect to acid-sulfate soils commmonly found in upstream freshwater areas of the delta. Component 2 represents the "photosynthetical factors": Chlorophyll, Primary Productivity, BOD5. The confinement index is also correlated, to a lesser extent, with this group of factors.

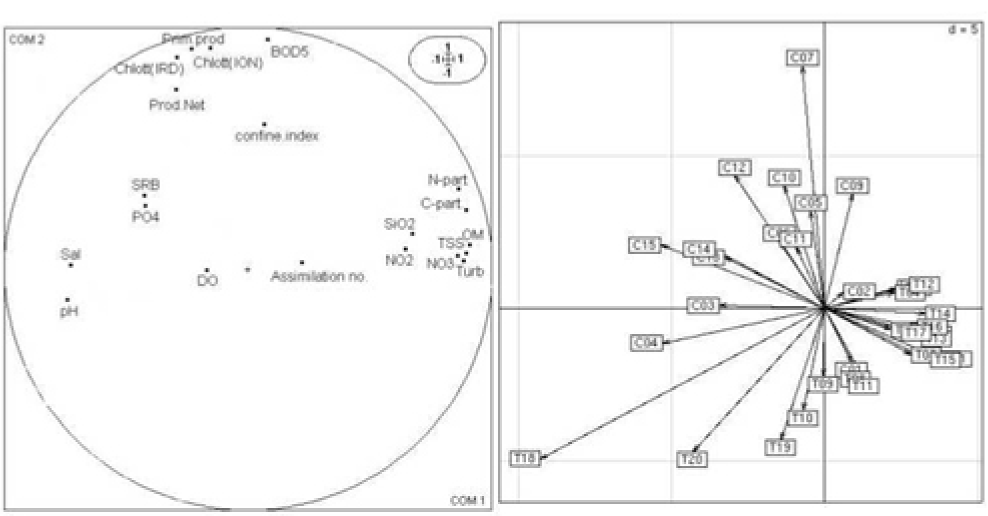

Figure 8: PCA first two components showing 21 variables (left) and 35 stations (right)

This means that at more confined stations, primary production develops better. This also shows that the CI, a very cheap parameter to establish, could be taken as a "proxy" variable to this group. The analysis shows that there is no relation between the "particulate" group and the "production" group, which vary independantly from each other.

The PCA also yielded a classification of the stations into seven hydrobiological zones (figure 8, right). Figure 9 shows the two sites of Tra Vinh and Camau, with their respective 20 and 15 stations. Yields were computed on all farms belonging to the each zone in two ways (table 1) a) the total yield of all crops extending over the dry season, b) the average yield per crop (which includes zero yield in cases of collapse). Note that in all instances, standard deviations are close to mean values, which indicates a very high dispersion.

Table 1: Yields statistics for sampled farms per hydrobiological zone (ref. Figure 9)

Zone		**Z1 CM**	**Z2 CM**	**Z3 CM**	**Z4 CM**	**Z5 TV**	**Z6 TV**	**Z7 TV**	**All sampled area**
Yield dry season (kg.ha-1)	Mean	55,18	60,72	134,33	156,03	352,22	706,32	278,32	284,26
	std	37,96	65,44	106,02	116,95	242,70	467,94	262,52	305,54
Aver.yield per crop (kg.ha-1)	Mean	14,76	14,09	57,87	46,26	255,87	616,32	215,81	200,09
	std	9,99	13,82	60,92	40,14	188,06	491,05	280,29	287,36

Three hydrological zones concern the Travinh site. The lower salinity found there is probably enough to discriminate them. Of particular interest is zone 6, where highest yield is encountered, which features very low TSS and high primary production. This has allowed some farmers to slightly intensify their activity, through higher stocking density, and hence reach higher yields. Zone 7 (Tra Vinh) exhibits even higher primary production, which triggers bacteria development at the expense of phytoplankton and therefore reduces yield. The Tra Vinh main river stations (zone 5) have consistent ecological conditions and an average yield per crop of 256 kg.ha-1.

The overall efficiency of Camau is much lower, with average crop values not exceeding 58 kg.ha-1, which indicates a high rate of collapses. This is mostly due to a higher accumulation of organic matter, probably adsorbed by particulate matter discharged from the Mekong river and deposited here over the years (Camau being the place where the Mekong delta develops

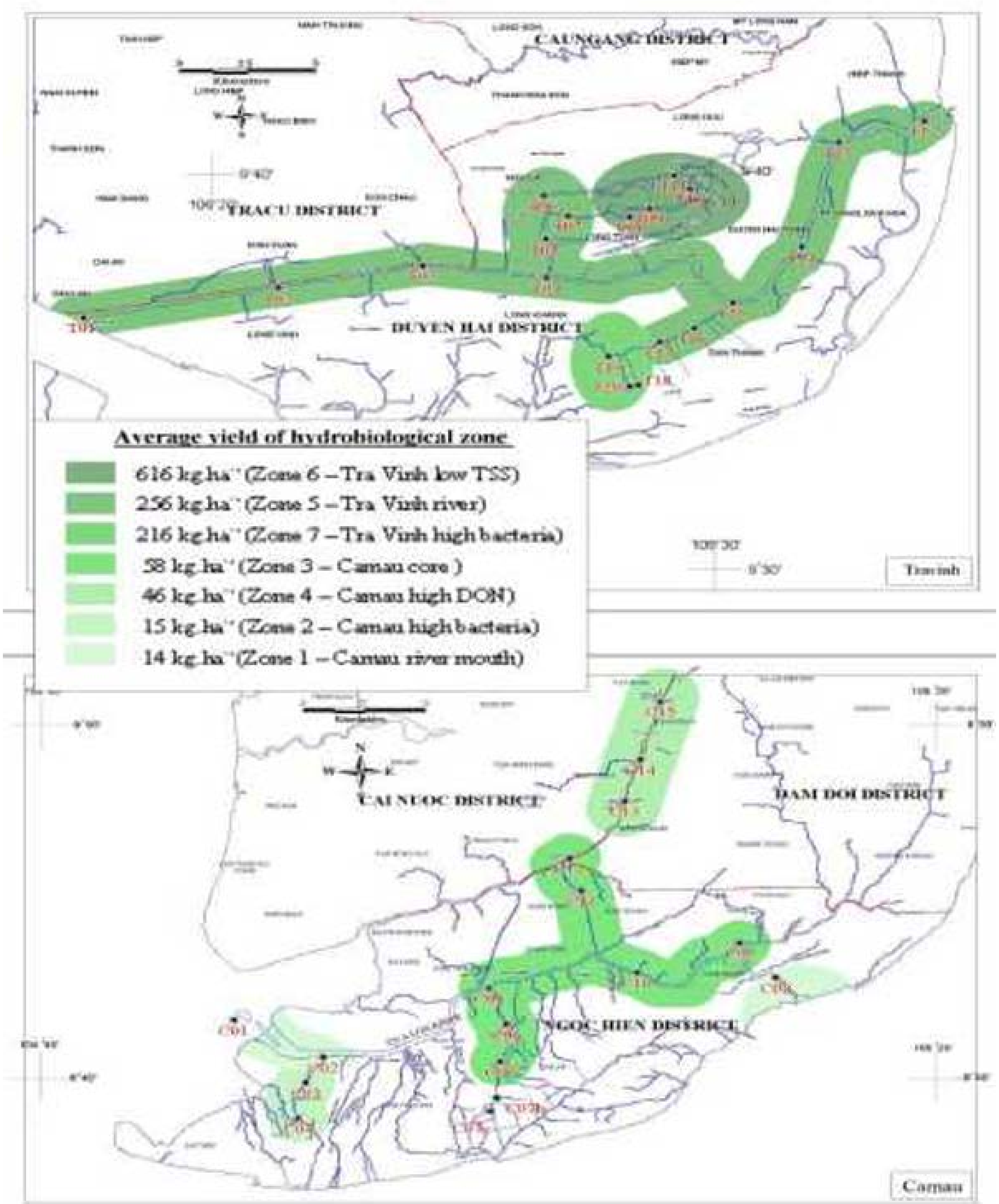

Figure 9: hydrobiological zonation of the two study sites, with yield (dry season 2002) as illustrative variable

and extends seawards). This results in lower dissolved oxygen and higher bacteria concentrations. A number of crop collapses occured in Camau, bringing down average yields to low levels. Note that yields for zones 4 and 5 are not significantly different. Besides, the results for zone 1 (made of station 2 only) are not significant. For zone 2, yields are extremely low, however these values should be regarded with caution in view of the reduced farm sample (only 10 farms).

Farms classification

The global classification carried out on the 160 farms, only based on their technical and management features, resulted in seven groups (figure 10). The variables "yield" (average yield per crop) and "profit rate" mapped here were not input to the analysis, but only set as illustrative variables. Figure 10 represents bar

charts superimposed on a background map, with colours displaying the seven farm categories and the height of the bars being proportional to either yield or profit rate. These groups of farms will not be detailed here. Looking jointly at figures 9 and 10, it is clear that the two classifications do not fully fit, as expected. Yet some striking points can behighlighted. For the four stations of zone 6 (see figure 9), the highest yield level (>500 kg.ha-1) is reached on 12 farms out of 20. This means that these farms were able to cope with the environment, adapting their zootechnical methods to reach a rather good production. However, when looking at profit rates, they reach the highest level for four of these farms only. This means that production costs could not be kept down.
Conversely in Camau, yields are far lower. None of them reaches the highest level and only a few the 3rd level (80-200 kg.ha-1). However profit rates are at 65% ot higher for 19 farms out of 75 (over 20%). These results question the soundness of "yield at all costs", proving that small-scale enterprises may be viable with low yields but good value-added.

Table 2 : farms statistics for hydrobiological zone 6, Tra Vinh

	Z6 Best	**Z6 Intermediate**	**Z6 Worst**
Farms number	13	4	3
Pond Area (ha)	1	1.42	0.3
Stocking Density (PL/m2)	6.5	4.6	9.5
Yield Monodon (Kg/ha)	984.5	283	65
Yield Wild (Kg/ha)	59	68.8	No Wild
Profit Rate	59%	15%	-96%
Technical efficiency (Kg/1,000 PL)	14.4	3.8	0.83
Survival Rate	38%	16%	3%
Nb of crops	1.8	1.75	1.7

With the second classification method, statistics were computed per zone, and worst and best farms binned together, while trying to detect the dominant zootechnical features of each bin. Three conspicuous zones are illustrated below. For zone 6 (table 2) three groups come out, which differ to a large extent for all performance variables (yield, survival rate and technical efficiency, profit rate), however no clear signal appear as how practices are relevant to performance. Reasonable stocking density can be advised (4 to 6 PL/m²), as well as continuous water renewal all along the crop by "topping up" water in the ponds. The conclusion is that the more suitable environment likely plays a key role in this zone, regardless of the practise/management which is applied, hence ensuring a majority of successful farms.

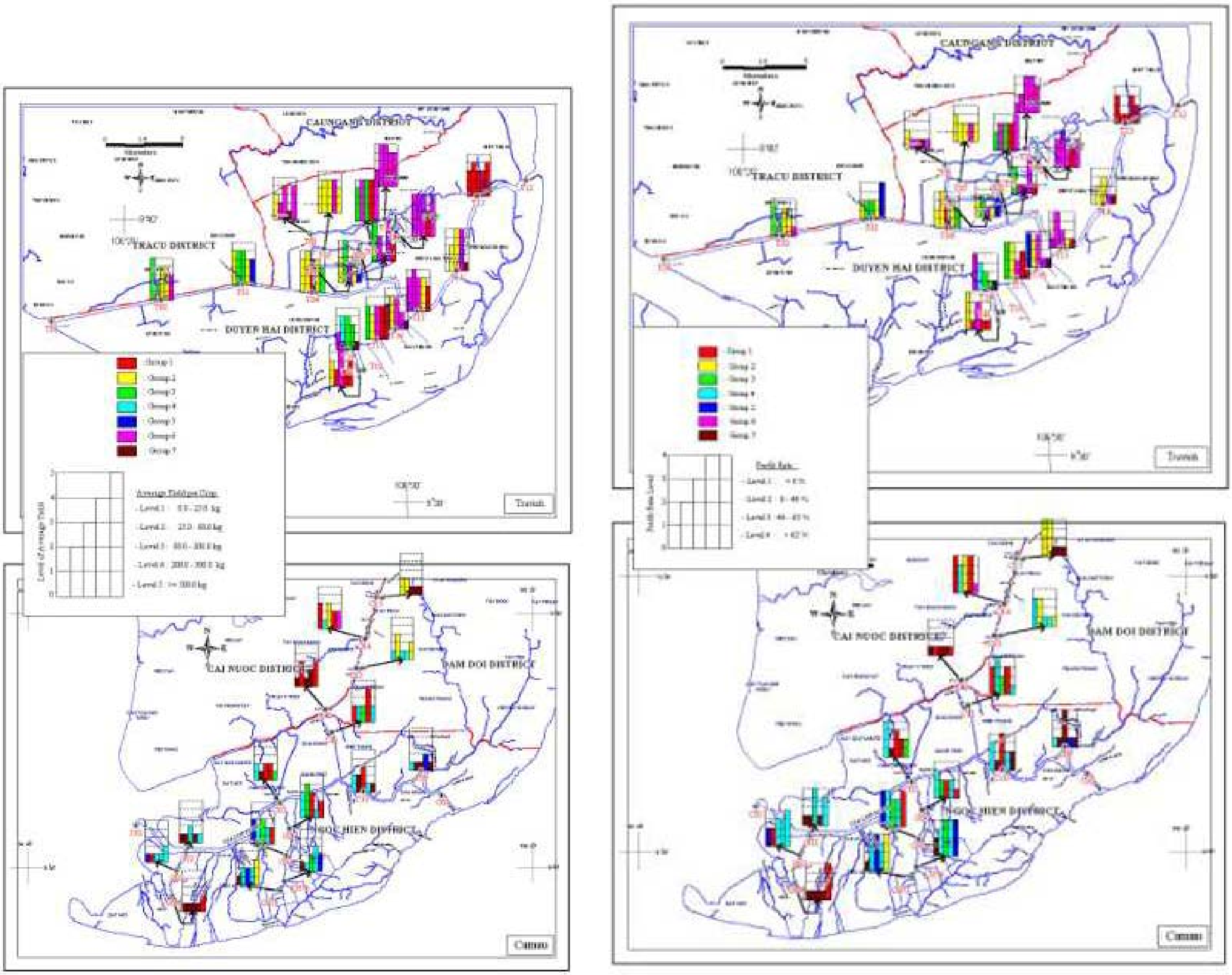

Figure 10: Yield and profit rate for farms in Travinh (left) and Camau (right)

Table 3: farms statistics for hydrobiological zone 4, Camau

	"Good" farms without wild species	"Bad" farms without wild species	"Bad" farms with wild species
Stocking Density (PL/m2)	1.7	3.6	1.7
Yield Monodon (Kg/ha)	185	63.8	63
Yield Wild (Kg/ha)	-	-	9
Technical efficiency (Kg/1,000 PL)	3.7	0.3	1
Profit Rate	71%	-93%	-17%
Profit /Kg (1.000 VND/Kg)	75	-73.5	-16.5
Nb of crops	2 to 3	3-4 to 5-6	5 to 6 mainly

The next example is zone 4 in Camau (table 3), an area of ongoing paddy to shrimp conversion. Here, good farms have reduced the number of crops to 2-3 and stocking density to below 1.5 PL/m² They use no feed nor chemicals. Good farms do not get a high technical success but rather thrive economically by keeping

costs at their lowest. The aim here would be, at low densities, to increase the survival rate in order to roughly double the yield. This, combined with the paddy income, should ensure good sustainability.
Hydrobiological zone 3 (table 4) contains basically two types of farms: in the north, two stations with farms recently converted from paddy, in the south seven stations with shrimp-mangrove as the dominant system, mainly under the integration scheme (mangrove inside ponds). Table 2 does not show large discrepancies between figures (yields are even highest in the worst farms!) except for survival rate, which when doubled is enough to allow the best farms to be profitable. The conclusion for this zone should also be to keep stocking densities low (<2PL/m²) and to avoid feeding. No conclusion can be drawn for other key management parameters, e.g. water management and post-larvae quality.

Table 4: farms statistics for hydrobiological zone 3, Camau

	Z3 Best	Z3 Intermediate	Z3 Worst
Farms number	20	6	19
Pond Area (ha)	1	2.65	1
Stocking Density (PL/m2)	2	5.5	2
Yield Monodon (Kg/ha)	116.8	170.1	140.7
Yield Wild (Kg/ha)	121.5	61.4	41.7
Profit Rate	45%	-13% but	-50%
Technical efficiency (Kg/1,000 PL)	1	1.4	2
Survival Rate	9%	4%	4%
Nb of crops	3	3.3	4

Conclusion
Although the environment is globally unsuitable, it is suspected to play a subtle role with respect to farming success. In some zones, the organic load is reduced and local conditions are improved, which makes the activity viable, yet with some limits. In some other zones (mostly Camau), none of the techniques reaches satisfactory yields, although some farms reach sustainability. The key point is to avoid collapses, which entail disruptions in farming life. The constant feature that appears from the study is that lower stocking densities are safer and that industrial feed is not to be advised. Some other observations concern water management (constant water level should be maintained), although farmers do not have any choice, being totally dependant on tide levels. Finally, the quality of PLs should be ensured, which is rather common sense than an actual observation.

6. General conclusion

Following reports of unstable and unevenly distributed yields of shrimp farming in the Mekong delta provinces, this study has attempted to give an account of some specific features of this activity, based on ecological, farming practise and socio-economic data. This work was based on the following statistical hypothesis: there is an underlying relation between shrimp yield and the quality of the hydrobiological environment, modulated by farm practises and management. This work has shown that shrimp aquaculture is "on the brink" in the Mekong Delta, the environment being unsuitable to aquaculture because of organic load in excess. Some sites are more suitable than others due to specific water circulation patterns that allow active primary production, the key factor for extensive aquaculture based on the trophic food chain.
Land cover maps have revealed that mangrove seemed to be detrimental to shrimp ponds yields, mostly in the widespread "mixed mangrove-shrimp system" of Camau where secondary mangrove are planted on about 70 % of the pond surface. This pattern may have to be reviewed in the future, by returning mangrove trees to tide-flooded grounds.
In spite of yields being quite low altogether, a number of farmers can still make a livelihood from low production by keeping their costs down. Very few farmers were successful in increasing their stocking densities, because simultaneously they used feed pellets and increased the organic load, thus leading to

eutrophication, animal stress and collapse. When they succeeded, most of the time their technical and economic efficiencies both remained low due to the fact that increases in costs outruled increases in revenues. This issue had been documented elsewhere (Fuchs, 1998). The rule seems to be to keep stocking densities within a low range, to apply simple and cheap practise, with basic environmental monitoring, and to avoid going into intensification, as encouraged by feed retailers.

Basic environmental monitoring could be implemented at local level by extension officers using a simple set of parameters, as recommended by the project. If site selection is needed in the framework of provincial planning, a more complex set of parameters is recommended, whose surveying would need the intervention of more specialized teams.

Finally, there seems to be a way in such deltaïc systems towards the mixed rice-shrimp system which ensures food security through rice production and limits risks associated with shrimp. However, more studies are necessary to determine which species are most adapted to low salinities.

Acknowledgments

We would like to thank the European Commission EuropAid Directorate, sponsor of this project.

Bibliography

- Beveridge, M.C.M., Phillips, M.J., Macintosh, D.J., 1997. Aquaculture and the environment: The supply of and demand for environmental goods and services by Asian aquaculture and the implication for sustainability. Aquaculture Research. 28. 797-807.
- Binh, C.T., Lin, C.K., 1995. Shrimp culture in Vietnam. World Aquaculture. 26 (4), 27-33.
- Chamberlain, G.W., 1997. Sustainability of world shrimp farming. In : Pikitch, E.K., Huppert, D.D., Sissenwine, M.P. (Eds.), Global Trends: Fisheries Management. American Fisheries Society Symposium 20, Bethesda, MD.
- de Graaf, G.J., Xuan, T.T, 1998. Extensive shrimp farming, mangrove clearance and marine fisheries in the southern province of Vietnam. Mangrove. Salt Mar. 2, 159-166)
- Fuchs, J., Martin, J.-L., Populus, J., 1998. Assessment of tropical shrimp aquaculture impact on the environment using hydrobiology, ecology and remote sensing as helping tools for diagnosis. Contrat Européen RS3-CT94-00284. Rapport interne de la Direction des Ressources Vivantes de l'Ifremer, 262 p.
- Johnston, D., Trong, N.V., Tien, D.V., Xuan, T.T., 2000. Shrimp yields and harvest characteristics of mixed shrimp-mangrove forestry farms in southern Vietnam: factor affecting production. Aquaculture. 188. 263-284.
- Kautsky, N., Ronnback, P., Tedengren, M., Troell, M., 2000. Ecosystem perspectives on management of disease in shrimp pond farming. Aquaculture. 191. 145-161.
- Nguyen D., 2002. Calculs hydrauliques du réseau de rivières dans la région littorale de la péninsule de Ca-Mau, Sud Vietnam. GAMBAS project contract report.
- Phuong, N.T., Hai, T.N., 1998. Coastal aquaculture and environmental issues in the Mekong Delta, Vietnam. In: Macintosh, D.J. (Ed.), TCE-P Workshop No II. "Coastal Environmental Improvement in Mangrove/Wetland Ecosystems". 18-23 August 1998, Royal Princess Hotel, Ranong, Thailand.
- Robert, R.J., Muir, J.F., 1995. 25 years of world aquaculture : sustainability, a global problem. In: Sustainable Fish Farming (ed. by H. Reinertsen & H. Haaland), pp. 167-182. A.A. Balkema, Rotterdam.
- Minh., T.H., Yakupitiyage, A., Macintosh, D.J., 2001. Management of the Integrated Mangrove-Aquaculture Farming Systems in the Mekong Delta of Vietnam. AIT ITCZM Monograph no.1.
- Thu Phan Minh, Populus J., Honda Kiyoshi, 2003. Using GIS and Remote Sensing Tools for Mangrove Forest Management in Tra Vinh, Vietnam. Submitted to Ocean and Coastal Management.
- Tong P. H. S. et al., 2003. Assessment from space of mangroves evolution in the Mekong delta, in relation with extensive shrimp-farming. Submitted to International Journal of Remote Sensing.