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Environmental quality and Farming practice in Mekong delta shrimp aquaculture : Statistical and GIS approach

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Abstract :
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Best local yields, computed at each water quality station were compared on maps of stations classified according to their water quality, land-use as well as maps of shrimp farm types. Shrimp yields along the main channels in Ca Mau and Tra Vinh are lower than in other areas (200-448.07 kg/ha). The level of TSS is inverse with the best local yield at water quality stations.

In Ca Mau, shrimp farms in the widespread mixed shrimp-mangrove system produce lower yields than shrimp farms recently converted from paddy. There are 14 shrimp farms identified as extensive shrimp farm with a very high stocking density (20.4 PL/m2), out of which nine (64.3%) produce the best yield at the station, (eight in Ca Mau and one farm in Tra Vinh). Shrimp farmers mostly in Ca Mau try to improve shrimp yield by increasing stocking density without changing pond design techniques. However, their efficiency remains low.

Mots-clés : shrimp aquaculture, water quality, multivariate analysis, GIS, Mekong delta

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Abbreviations and notions

Acclimatization	The process to acclimate post larvae before dropping into shrimp ponds
Assimilation number	The ratio of primary productivity/chlorophyll total
BOD5	Biochemical Oxygen Demand (5 days)
Brackish water	Slightly salty water
Eigen value	The variance extracted by the components
CA	Cluster Analysis
Farming practice	The way to manage shrimp farm
GAMBAS	Global Assessment of Mekong Brackishwater Aquaculture of Shrimp
IFREMER	Institut français de recherche pour l'exploitation de la mer
NIO	Institute of Oceanography, Nha Trang
PCA	Principal Components Analysis
PL	Post larvae
SRB	Sulphate Reducing Bacteria
Stocking density	Number of post larvae per area
Yield	The quantity of product at the given area or in a given time

1. Introduction

1.1 Shrimp Aquaculture in the Mekong Delta

Over the last twenty years from 80 decades, shrimp aquaculture has been developing rapidly in Asian region, including in Vietnam. Rapid expansion has resulted high production, currently ranking seventh in total global shrimp production (Kautsky et al., 2000). The lengthy coastline of Vietnam can be divided into three zones based on climatic and ecological conditions for shrimp aquaculture: Northern, Central and Mekong Delta.

The Mekong Delta is the largest potential area for shrimp aquaculture. Shrimp farming is operated in 5 systems, extensive, improved extensive, semi-intensive, shrimp-mangrove and shrimp-rice culture systems. The total production of shrimp aquaculture in the Mekong Delta achieved 48,664 mt in 1997 (Johnston et al., 2000; Phuong and Hai, 1998). Shrimp production varied among the various shrimp culture systems with semi-intensive farms producing 1,000-2,000 kg/ha/yr, and extensive farms 100-400 kg/ha/yr (Binh and Lin, 1995). The principal shrimp farming system in the Mekong delta are in form of extensive aquaculture which relies on tidal recruitment of wild seed and stocking of hatchery-reared postlarvae at low densities with minimum of feed supply. Water exchanging usually occurs during spring tide (Binh and Lin, 1995). This means that the shrimp production is almost supported by primary production via the food web.

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 yields and low efficiency. Shrimp farmers attempts to develop the level of intensification from extensive to semi-intensive or intensive systems have led to many collapse. The decrease of shrimp yield in the Mekong delta is reported over 10 years (Table 1.1).

Table 1.1 : Average yield in Minh Hai province

Year	Average Yield (kg/ha/year)
1990	408
1991	476
1992	387
1993	305
1994	234
1995	219
1996 (Ca Mau separated from Minh Hai)	262

Source : Final scientific report of STD3 programme (1998)

The Vietnamese authorities demand is to protect the ecosystem while sustaining this activity on a long-term basis to provide sufficient income to the local population and avoid rural depopulation

There are many important factors affecting shrimp production. Farming production not only depends on the ecological service supplied by nature but also on the capacity of farming practice: pond depth, pond area, stocking density, chemicals used etc. (Kautsky et al., 2000). Viral and bacterial disease together with poor soil and water quality, are the main causes of shrimp mortality (Liao, 1989; Chamberlain, 1997).

1.2 Sustainable Shrimp Aquaculture

The concept of sustainability remains unclearly defined in aquaculture. One definition of sustainable aquaculture might incorporate social, technical, financial and ecological concerns (Roberts et al., 1995; Beveridge et al., 1997; Doupé et al., 1999). Sustainability does not depend on the level of intensity, but rather on the suitability of the technology and the quality of the farming site (Hambrey, 1996). There is an explicit relationship between aquaculture and its surrounding environment because aquaculture relies on a wide range of natural resources and environmental goods. Beyond the economic and logistic feasibility of the venture, the two fundamental requirements for a sustainable aquaculture industry are the appropriate use and management of the land and water resources. Site selection is the first important criterion for sustainable aquaculture and can be guided or encouraged by government through incentives, education and information.

1.3 The GAMBAS Project

The GAMBAS "Global Assessment of Mekong Brackishwater Aquaculture of Shrimp" project is a co-operation project between IFREMER and NIO (Nhatrang Institute of Oceanography). GAMBAS is being carried out during 2000 - 2003. The overall objective is to promote the sustainable development of shrimp brackish water aquaculture in the Mekong delta by avoiding ecosystem degradation and further production collapse.

Variation of shrimp production in the Mekong delta has induced some questions to the Vietnamese authorities :

- Why are some sub-areas globally non-productive? Is the environment non-suitable to shrimp farm in some locations ?
- How come such discrepancies are reported between sub-areas within the sites or even between close-by farms ? Given the postulate that neighbour farm should share the same environmental conditions, is there a way to explain why some of them fail ?

Shrimp production in extensive or improved extensive system depends on three main categories of parameters (Figure 1.1).

- Ecological condition of farming site
- Farming practice
- Socio-economics

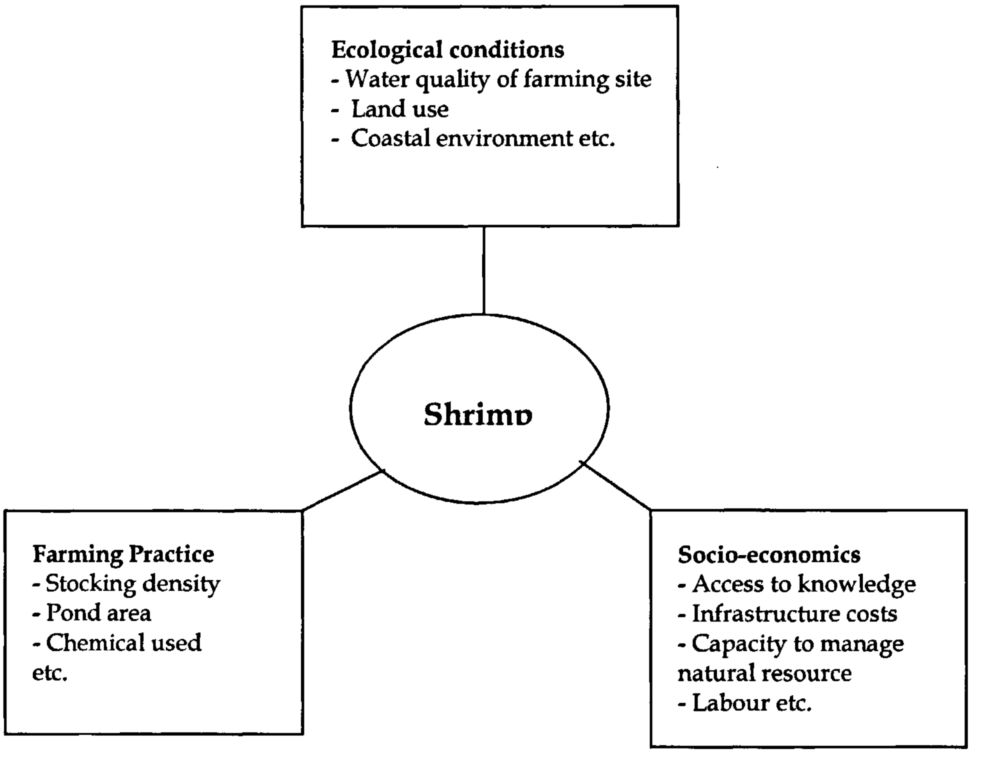

Figure 1.1 : Main factors affecting shrimp production in extensive systems

Four activities have been conducted in objective to assess the shrimp farming status in the Mekong delta as follows :

Activity 1 : Water quality survey
Activity 2 : Farming practice and socio-economics of shrimp farming
Activity 3 : Land ecosystem and land-use mapping
Activity 4 : Integration of results, data analysis and interpretation.

Activity 4 is the objective of this study. There are many data involved in shrimp farming management. In order to collect and prepare data for analysis easily and effectively, a database has to be organized. For analysis many variables simultaneously, multivariate analysis techniques were selected.

There are several studies which had been carried out in the Mekong delta in order to improve shrimp aquaculture or investigate the main factors affecting shrimp production. Although many studies present results in the form of reports, descriptions, even statistical data, quite few actually present it using mapping techniques. In the last step the results of this study were presented on geographic scale as information for supporting planning and management.

1.4 Objective of the study

This study aims at assessing shrimp aquaculture status based on ecological and farming practice aspects in two study areas, namely :

- by assessing environmental quality suitability of study area to shrimp aquaculture,
- by assessing shrimp farming practice in study areas,
- by presenting the information on geographic scale as a support to planning and management.

2. Study areas

The study sites, TraVinh and Camau provinces, are situated in the Mekong Delta (Map 1, Appendix 6). The two adjacent seas, South China Sea in the East and the Gulf of Thailand in the West, influence this area with the complex interaction from two different tidal regimes. Tide is semi-diurnal with an amplitude of 3-3.5 m in South China Sea and diurnal with an amplitude of 1.1-1.2 m. in the Gulf of Thailand. The climate is tropical influenced by monsoon. There are two seasons, dry (North-easterly monsoon) and rainy (South-westerly monsoon) on December-April and May -November, respectively.

2.1 Ca Mau

Ca Mau is the southernmost province situated in the tip of the Mekong peninsula. The coastal line of 254 km creates a coastal area of 154,000 ha or 29.7 % of the total area. The waterways are composed of rivers and canals throughout the province. This area is under prevailing marine influence and the rainy season has been shown to have little influence on flow in waterways (Nguyen, 2002). The general shrimp farm system is integrated-mangrove shrimp farming with quite simple techniques, i.e. no liming, fertilizing and feeding. Spot4 satellite image (dated April 10, 2001) illustrate shrimp farms distribution located in mangrove zone (Map A, Appendix 5).

2.2 Tra Vinh

Tra Vinh is situated between two branches of the Mekong river, Co Chien River in the East and Hau Giang River in the West. These main rivers affect this part of the delta in such a way that is much less salted than the Ca Mau zone especially in rainy season. The system of rivers, canals and sea in Tra Vinh create an appropriate environment for aquaculture activity. Aquatic products reaching 90,000 tons of shrimps and fish were produced by this province during period 1996-2000.

3. Data used

3.1 Environmental quality

Water quality

Two surveys were carried out in October 2001 and March 2002 to be representative of rainy and dry seasons respectively. Water parameters were measured at 35 stations in 2 study areas (Map 2 and 3, Appendix6). These stations have originally been chosen covering the widest variability in terms of water ecology. Water samples were collected during high tide at level 0 and 2 m from surface, corresponding to the most likely period for water renewal to shrimp ponds. Parameters analysed and units are indicated in table 3.1.

Table 3.1 : Water parameters collected at stations

Water parameter	Unit
Dissolved oxygen	mg/l
Temperature	° C
Salinity	ppt
pH	
Turbidity	NTUs
Total Suspended Solid (TSS)	mg/l
Organic Matter	mg/l
Organic Carbon Particulate	µg/ml
Nitrogen Particulate	µg/ml
Chlorophyll total	µg/ l
Primary productivity	mgC/m3/h
Ammonia (NH3, NH4)	µg/ l
Nitrite (NO2)	µg/ l
Nitrate (NO3)	µg/ l
Phosphate (PO4)	µg/ l
Biochemical Oxygen Demand (BOD5)	mgO2/l
Assimilation number	-
SRB	cell/ml
Net primary producitivity	mgC/m3/d

Confinement index

A "Confinement index" was used as an indicator reflecting the rate of water renewal within waterways and channels. It will determine the ecosystem capacity to assimilate or evacuate the wastes issued from the aquaculture activity. In this study, the index was computed from the ratio of the distance to the sea over cross section of the canal at the given point. (For more detail see Appendix 2)

3.2 Farming Practice

Groups of shrimp farm were selected in the vicinity of the station (usually 4 farms per station) for collecting farming practice, socio-economics, shrimp production on rainy and dry season. The survey was performed in March 2001 using a questionnaire for interviewing the farmers of 121 farms.

The variables based on farming practice were selected for conducting shrimp farm classification (Table 3.2).

Table 3.2 : Farming practice variables selected for farm classification

Farming practice	Unit
Stocking density	PL/m2
Pond area	ha
PL age	day
Pond age	year
Pond depth	meter

3.3 Geographic information and satellite imagery

Spatial data was used in this project on purpose to produce a map for presenting the results as a geographic information in order to better understand the interaction between data sets and to be an information supporting planning and management. The conclusion on shrimp farming status can be summarized by gathering information on geographic scale from different aspects together.

Satellite imagery

Two pseudo-10 meter Spot4 scenes, XS spectral mode were acquired on 10 April 2001 for Ca Mau and 22 January 2001 for Tra Vinh. The images were processed in colour composite mode bands 3,2,1 (RGB). They were used in the study for two purposes.

- To provide a base map for computing the "hydraulic" distance to sea of water quality stations using the fine perception of the waterway network as a qualitative support in order to calculate a confinement index.
- To establish a land use map of study area for featuring the main land use unit and the most recent changes undergone by the area e.g. conversion of paddy or some mangrove areas to shrimp culture.

Various attempts had been made to obtain the land use maps by the GAMBAS project participants. A maximum-likelihood classification was first used. It gave a reasonable account of the land-use in Tra Vinh . In Ca Mau, giving the sub-pixel size of most objects in the widespread mixed sylvi-shrimp culture system. The interpretation using ground-truth information was applied in the next

step. They gave an overall zonation which clearly split Ca Mau stations into three zones (Map
B, Appendix5), while most Tra Vinh belong to the zoneII (MapC, Appendix5).

Waterways

Waterways in two study areas were drawn by using satellite images.

District boundaries

District boundariess used to produce maps for presenting the results. It was produced by the Vietnamese participants (NIO).

4. Methodology

The methodology applied for this study is divided in 4 main parts :

- Build up a database for storing data from each activity of GAMBAS project and prepare data by querying before analysis step.
- Data analysis on environmental data (water quality) performed by multivariate analysis technique, i.e. Principal Components Analysis (PCA) and Cluster Analysis (CA)
- Data analysis on farming practice using CA
- Map production of environmental conditions and farming systems of study areas.

4.1 Database design

In this study a database was set up in order to store data from all GAMBAS project activities.

The main activity of GAMBAS project was to carry out surveys for collecting data by each project team. In the objective to analyse data for assessment of shrimp farming status, data from each activity will be integrated on analysis. It is necessary to organise database for storing, manipulating and preparation data before analysis. The retrieval for analysis purpose or exchange among project team can be done effectively by querying.

4.1.1 Data modelling

In this study water quality data was collected at stations identified by their locations. Farming practice and socio-economic data were gathered by questionnaire. In order to design database, data modelling technique was applied. Various level of data modelling will be explained in the following;

Conceptual data modelling

The objective is to create a conceptual scheme for database using "Entity Relationship (ER) modelling". Entities are spatial or non-spatial object whose characteristics are collected. In this study, the main entities are water sampling station and shrimp farm (Figure 4.1).

Logical data modelling

ER is transferred for implementation data model on DBMS. Using relational data model, data are organised in tables. Many to many relationships have to be normalised.

Physical data modelling

This step includes effective data storage and organize database. Attribute data in this project will be stored in tables.

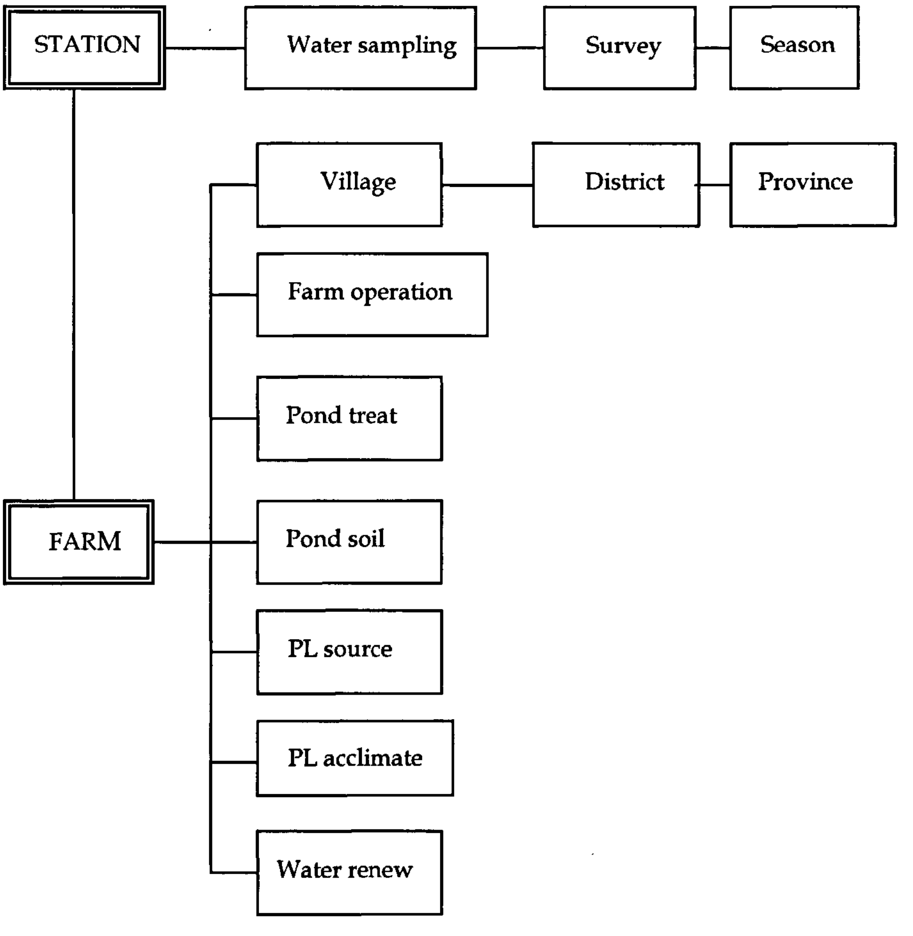

Figure 4.1 : Structure of project database

Software used: MS Access2000 was used for manipulating project database. Excel2000 was used for collecting and preparing data before importing to database.

4.2 Data Analysis

4.2.1 Classification of water quality stations

The aim of water quality classification is to group similar environmental conditions together. After that, shrimp yields among groups will be considered and compared for a decision as to which group has better condition for shrimp farming. Water quality data in dry and rainy seasons from 35 stations in two study areas were used. In each season 21 water quality variables (physical, chemical and biological parameters) were measured at each station. It is too difficult to process all variables together and many variables are correlated to each other. Multivariate statistical technique is used for reducing data dimension (reduce variables) in order to detect the structure and relation among variables.

Multivariate statistical analysis is concerned with datasets that have more than one response variable for each observational or experimental unit. It is the proper technique developed to deal with situations in which there are two or more variables that we would like to analyse simultaneously. They can be divided in two broad categories, regression type and ordination type (for more detail of multivariate analysis see Appendix1). In order to classify water quality stations two multivariate analysis techniques were applied as follows :

Principal Component Analysis (PCA)

The concept of PCA is a technique applied for compressing a set of variables into a smaller number of derived variables or components. The derived components are normally distributed and uncorrelated (orthogonal). It is used to pick out patterns in the relationships between the variables in such a way that most of the original information can be represented by a reduced number of new variables (for more detail see Appendix1).

PCA was performed on water quality data in dry and rainy seasons. The objective is to reduce the number of variables and investigate the relations and data distribution between two study areas and two seasons. Correlation matrix was used in PCA because the variables were measured in different units. The main components retained from PCA will be used as guidelines for selecting variables to be criteria for classification in the next step.

Cluster analysis (CA)

The aim of cluster analysis is to classify a data set into groups that are internally cohesive but externally isolated. Water quality stations were clustered according to variables selected from PCA results and a priori knowledge. The important concept was applied to perform CA as follows :

Standardization of data

Cluster analysis can accept a wide variety of input data. If these are variables measured on different scales, the one possibility is using standardised data. Water quality data set was composed of many variables measured in different units. The most common forms of standardization is placing on a 0-1 scale according to the formula:

$$X_{std} = \frac{(x - \min)}{(\max - \min)}$$

Distance measuring

Euclidean method was selected in this analysis. The distance between data was measured as a straight line in multidimensional space.

Lingkage type

Ward's method, the sum of squares method, was selected. Cluster membership is assessed by calculating the total sum of squared deviations from the mean of cluster. The criterion for fusion is that it should produce the smallest possible increase in the sum of within-group sums of squares.

The classification will be conducted with water quality data in dry season since it is known shrimp aquaculture activity is preferably conducted during the dry season. CA was performed using hierarchical agglomeration method with standardised matrix, Euclidean distance, Ward's method linkage.

4.2.2 Classification of Shrimp farms

Farming practice data were selected as criteria for classification of shrimp farms in order to investigate techniques used by shrimp farmers in the study area. Five important variables based on pond structure and farmers technique were chosen: stocking density, pond area, pond depth, pond age and PL age. All variables were standardized before analysis by the same formula as water quality data. Cluster analysis was performed using hierarchical agglomeration method with standardized matrix Euclidean distance and Ward's method linkage.

Software used : Data analysis on multivariate statistical technique using Splus.

4.2.3 Database update and Map production

The results of water quality stations groups and shrimp farms groups acquired from the analysis will be stored in the database.

Maps were produced to present the results from data analysis. Shrimp farm systems based on farming practice variable, groups of water quality condition and land use map units will be compared with shrimp yields in order to assess shrimp farming status in study area.

Software used : Arcview 3.2 was used for editing spatial data and producing the map.

5. Results and Discussion

5.1 Database

A list of entities, their identifiers and attributes is given in Table 5.1. The abbreviations used are explained in Appendix 3.

Table 5.1 : The entities, identifiers and attributes of the database

Entities	Identifiers	Attributes
Station	code_station	lat, long, tidal_range, cross_section, distance to sea, point to sea, confine_index, G_wquality
Water sample	Idw	code_station, date, time, code_survey, depth, level, diss_oxy, temp, conduct, salinity, pH, turbidity, TSS, Org_Mat, OM in TSS, N_part, C_part, C/N, pico_cyano, micro_cyano, pico_eucar, hetero_bact, chlott_IRD, prim_prod(IRD), AssimNO, chlott_ION, p_gross, p_net, p_resp, NH3-4, NO2, NO3, PO4, SiO2, BOD5, COD, Vibrio, SRB
Farm	code_farm	code_station, code_village, Nb of sluice, Nb of pond, pond age, pond depth, code_treatment, code_soil origin, code_PLsource, PL age, code_acclimate, code_water renewal, water exchange, G_fpractice
Farm operation	Idf	code_farm, code_survey, labour cost, depreciation, total cost, profit rate, farm area, yield, SD, eff_index, survival rate
Pond treatment	code_treatment	pond_treatment
Pond origin	code_soil origin	Pond soil origin
PL source	code_PLsource	source of PL
PL acclimatization	code_acclimate	Time
Water renewal	code_renewal	water renewal
Survey	code_survey	time survey, code_season
Season	code_season	Season
Village	code_village	village, code_district, code province
District	code_district	District
Province	code province	Province

5.2 Water quality analysis

5.2.1 PCA Analysis

PCA was selected for analysis water quality variables on purpose to reduce the data dimensionality. Two sets of 35 stations data measured from field surveys on October 2001 and March 2002 were analysed.

The component to be retained are based on the basis of the shape of the decrease in the eigen values according to the criteria proposed by Cattell, 1966. In this analysis, three principal components were retained. The details of standard deviation and variance of principal components are presented in Table 5.2. Theses three axis accounted for 70% of the total population (Figure 5.1). The analysis can explain the correlation among parameters in the main components (Figure 5.2.1).

Coml : There are strong correlation of particulate variables: Turbidity, Total Suspended Solids, Organic Matter, Nitrogen particulate, Carbon particulate and Nitrate (NO3). Salinity and pH are correlated with each other and discorrelated to the particulate group.

Com2 : Represent "photosynthesis factors": Chlorophyll, Primary productivity, BOD5. Confinement index is correlated with this group of factors.

Com3 : Assimilation No. discorrelated to SRB and salinity

Table 5.2.1 : Standard deviation and variance proportion of principal components

Principal components	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp. 5
Standard deviation	2.686	2.140	1.461	1.264	0.977
Proportion of variance	0.360	0.228	0.106	0.079	0.047
Cumulative proportion	0.360	0.589	0.696	0.776	0.824

The PCA results identify the effect of season on water quality change and distribution in both study area. Tra Vinh is affected by season in a stronger way than Ca Mau (Figure 5.3, 5.4).

The correlation matrix can be seen in table 5.2.2.

Figure 5.1 : Percentage of variance of principal components

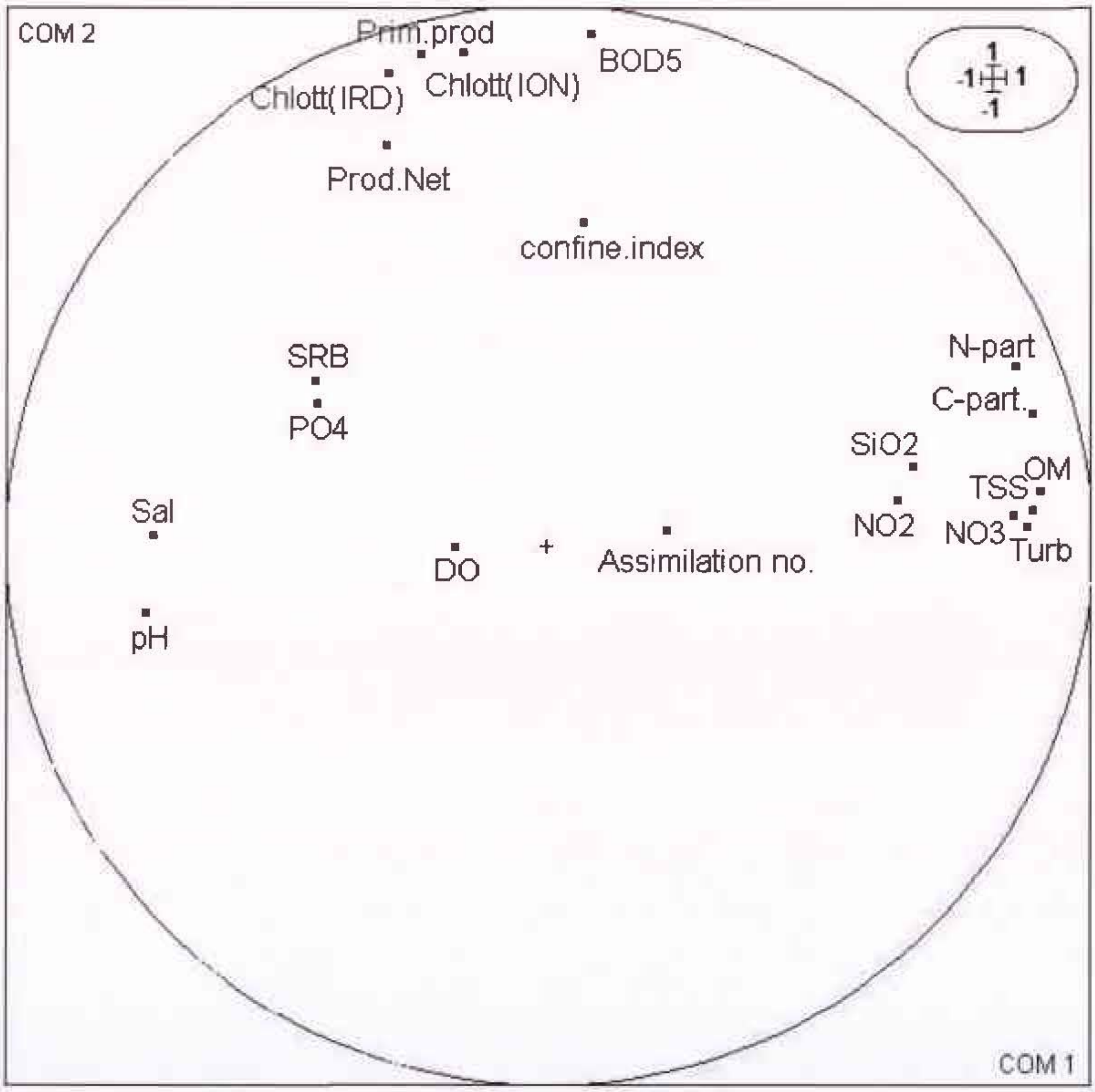

Figure 5.2 : Biplot of water quality variables on components 1 and 2

Table 5.2.2 : Correlation matrix of water quality parameters

	DO	Sal	pH	Turb	TSS	OM	N.part	C.part	Chlo.IRD	Prim	Chlo.ION	P.Net	Ass.no	NO2	NO3	PO4	SiO2	BOD5	SRB	confine
DO	1.00	-0.08	0.40	-0.01	-0.07	-0.06	-0.11	-0.14	0.16	0.04	0.14	-0.12	-0.36	-0.08	-0.19	0.16	0.05	-0.05	0.09	-0.17
Sal	-0.08	1.00	0.62	-0.46	-0.43	-0.49	-0.43	-0.47	0.19	0.07	0.06	0.28	-0.33	-0.56	-0.61	0.28	-0.92	0.00	0.45	0.03
pH	0.40	0.62	1.00	-0.45	-0.48	-0.51	-0.53	-0.55	0.16	-0.03	0.06	0.05	-0.39	-0.61	-0.60	0.42	-0.65	-0.24	0.39	-0.16
Turb	-0.01	-0.46	-0.45	1.00	0.97	0.95	0.88	0.89	-0.20	-0.25	-0.12	-0.24	-0.04	0.44	0.69	-0.25	0.42	0.07	-0.15	0.00
TSS	-0.07	-0.43	-0.48	0.97	1.00	0.97	0.90	0.94	-0.22	-0.25	-0.11	-0.21	0.05	0.41	0.70	-0.24	0.38	0.11	-0.16	0.07
OM	-0.06	-0.49	-0.51	0.95	0.97	1.00	0.92	0.95	-0.18	-0.19	-0.06	-0.18	0.10	0.39	0.70	-0.26	0.44	0.15	-0.20	0.08
N.part	-0.11	-0.43	-0.53	0.88	0.90	0.92	1.00	0.97	0.05	0.03	0.17	-0.01	0.06	0.44	0.72	-0.23	0.43	0.37	-0.11	0.20
C.part	-0.14	-0.47	-0.55	0.89	0.94	0.95	0.97	1.00	-0.07	-0.07	0.07	-0.06	0.14	0.40	0.73	-0.25	0.44	0.28	-0.14	0.17
Chlo.IRD	0.16	0.19	0.16	-0.20	-0.22	-0.18	0.05	-0.07	1.00	0.87	0.87	0.63	-0.24	-0.09	-0.20	0.32	0.00	0.76	0.37	0.42
Prim	0.04	0.07	-0.03	-0.25	-0.25	-0.19	0.03	-0.07	0.87	1.00	0.85	0.74	0.02	0.00	-0.12	0.28	0.10	0.85	0.21	0.46
Chlo.ION	0.14	0.06	0.06	-0.12	-0.11	-0.06	0.17	0.07	0.87	0.85	1.00	0.65	0.00	0.01	-0.08	0.27	0.04	0.81	0.28	0.45
P.Net	-0.12	0.28	0.05	-0.24	-0.21	-0.18	-0.01	-0.06	0.63	0.74	0.65	1.00	0.11	-0.22	-0.22	0.18	-0.15	0.68	0.35	0.23
Ass.no	-0.36	-0.33	-0.39	-0.04	0.05	0.10	0.06	0.14	-0.24	0.02	0.00	0.11	1.00	0.00	0.13	-0.32	0.19	0.10	-0.21	0.16
NO2	-0.08	-0.56	-0.61	0.44	0.41	0.39	0.44	0.40	-0.09	0.00	0.01	-0.22	0.00	1.00	0.65	-0.17	0.52	0.10	-0.43	0.15
NO3	-0.19	-0.61	-0.60	0.69	0.70	0.70	0.72	0.73	-0.20	-0.12	-0.08	-0.22	0.13	0.65	1.00	-0.32	0.57	0.12	-0.39	0.07
PO4	0.16	0.28	0.42	-0.25	-0.24	-0.26	-0.23	-0.25	0.32	0.28	0.27	0.18	-0.32	-0.17	-0.32	1.00	-0.20	0.18	0.34	0.11
SiO2	0.05	-0.92	-0.65	0.42	0.38	0.44	0.43	0.44	0.00	0.10	0.04	-0.15	0.19	0.52	0.57	-0.20	1.00	0.16	-0.35	0.04
BOD5	-0.05	0.00	-0.24	0.07	0.11	0.15	0.37	0.28	0.76	0.85	0.81	0.68	0.10	0.10	0.12	0.18	0.16	1.00	0.20	0.55
SRB	0.09	0.45	0.39	-0.15	-0.16	-0.20	-0.11	-0.14	0.37	0.21	0.28	0.35	-0.21	-0.43	-0.39	0.34	-0.35	0.20	1.00	0.09
confine	-0.17	0.03	-0.16	0.00	0.07	0.08	0.20	0.17	0.42	0.46	0.45	0.23	0.16	0.15	0.07	0.11	0.04	0.55	0.09	1.00

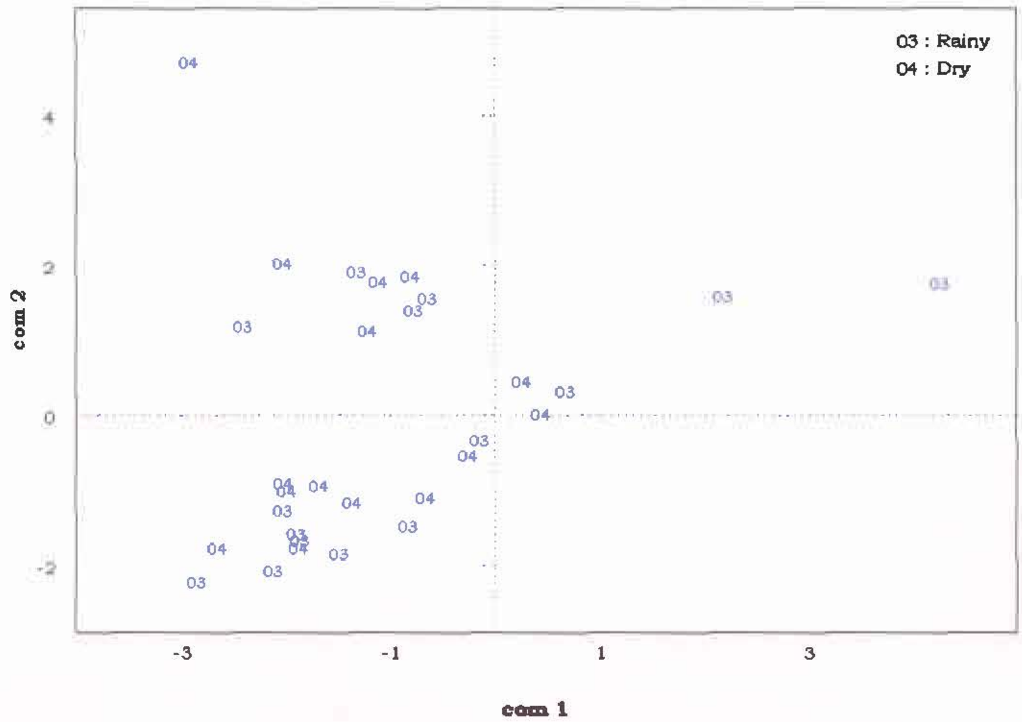

Figure 5.3 : Bidimensional PCA representation of water quality Distribution in dry and rainy seasons of Ca Mau

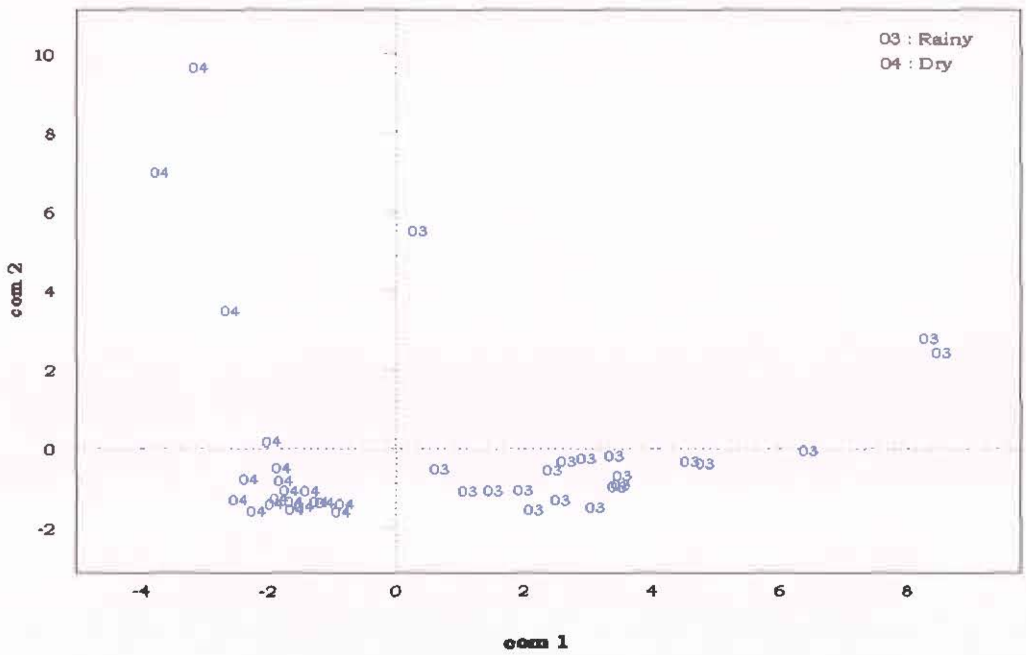

Figure 5.4 : Bidimensional PCA representation of water quality distribution in dry and rainy seasons of Tra Vinh

5.2.2 Classification of water quality stations

PCA analysis can explain the structure and relation of data in study area. From the principal components the parameters most relevant to shrimp farming: Salinity, TSS, Chlorophyll total, Primary productivity, BOD5 and SRB were selected as criteria for grouping station in cluster analysis (CA).

For retaining the number of clusters in CA, the principle is to choose a place where the cluster structure remains stable for a long distance. Some other possibilities are to look for cluster groupings that agree with expected structures or to see if the structures emerge consistently.

Seven clusters of water quality were retained from hierarchical cluster analysis as shown in dendrogram (Figure 5.5). Salinity was the main factor separating groups between Ca Mau and Tra Vinh with value higher than 27 ppt and lower than 20 ppt respectively. Stations T18, T19 and T20 of Tra Vinh (cluster A) were separated because of the high level of primary productivity and chlorophyll total.

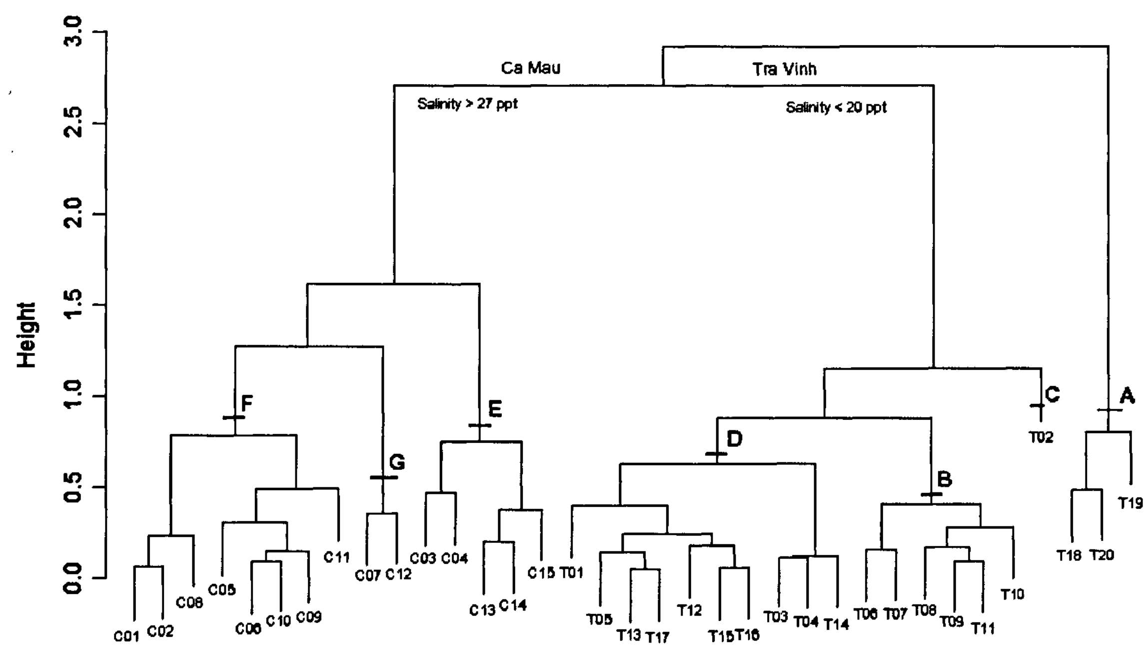

Figure 5.5 : Groups of water quality stations obtained by cluster analysis

In order to rank the water quality groups, the best local yield in each station was selected instead of average yield because there is a high variability of shrimp yield among farms in the study area (Appendix 4). At this point the farming practice among best yield farms should not interfere much as we suppose these best yield farms should have a "good" technique.

Water quality groups are characterized by six original variables and average of the best local yields in each cluster (Table 5.3). The distribution of the cluster members in study area with the best local yield in each station were shown in Map 4 and 5, Appendix 6.

Table 5.3 : Characteristic of the water quality clusters identified by cluster analysis

Cluster	Size	Avg. of best Yield (kg/ha)	TSS (mg/l)	Sal (ppt)	Prim. prod. (mgC/m3/h)	Chlorophyll (µg/l)	BOD5 (mgO2/l)	SRB (cells/ml)
A	3	685.00	40.97	19.67	229.67	57.73	3.66	156.67
B	6	630.42	46.32	19.32	46.17	8.42	1.00	73.33
C	1	600.00	83.20	19.20	32.00	5.40	1.06	318.00
D	5	586.33	147.91	29.22	105.80	21.32	2.56	98.00
E	10	448.07	160.83	17.48	20.40	4.42	0.58	61.50
F	8	446.20	167.63	27.50	19.03	5.66	0.66	98.75
G	2	200.00	462.72	28.20	25.25	6.70	1.25	175.00

Cluster A : The most suitable water quality for shrimp aquaculture characterized by high level of primary productivity (229.67 mgC/m3/h) and chlorophyll total (57.7 µg/l). Station T18, T19 and T20 belong to this cluster.

Cluster B : The water quality of this group is close to cluster A but with lower in primary productivity and chlorophyll total. Station T06, T07, T08, T09, T10 and T11 are located in this cluster.

Cluster C : The parameter distinguishing this cluster (T02) from the main channel (cluster E) is the highest level of SRB (318 cells/ml) and lower TSS. Station T02 belong to this cluster.

Cluster D : The cluster members are located along Bay Hap river in the north and Ong Trang branch in the South of Ca Mau province. The parameters characterize this cluster with highest salinity (29.2 ppt), high TSS (147.9 mg/l) and high primary productivity (105.8 mgC/m3/h). This cluster is composed with C03, C04, C13, C14 and C15.

Cluster E : Almost all stations in this cluster are located along the main channel Quan Chanh Bo branch, Lach Sac branch, Sau branch and Lang Nuco river traversing Tra Vinh province. It is the least suitable area in Tra Vinh with level of TSS 160.83 mg/l. (Stations T01, T03, T04, T05, T12, T13, T14, T15, T16, T17).

Cluster F : High level of Salinity and TSS, low level of primary productivity. All of stations are located in Ca Mau province C01, C02, C05, C08 and C09 in Cua Lon river, C06 in Ong dinh branch and C11 in Ngang channel.

Cluster G : The water quality is least suitable for shrimp aquaculture, with the highest of TSS (462.72 mg/l) and low primary productivity. C07 and C12 are located in this group.

The best local yields in each station in Ca Mau and Travinh were illustrated on land use map established by ground-truth interpretation. In Ca Mau (Map 6, Appendix 6), we found that best local yield is found in farms recently converted from paddy to shrimp farm (cluster D) except for C03 and C04 (located in the mixed system). Groups F and G (low shrimp yield) include most of the mixed mangrove system (C01, C02, C05, C06, C08, C09 and C11) except C12. In Tra Vinh, it is not clear to explain the shrimp yield differentiation in term of land use aspect as in Ca Mau but the high shrimp yield (cluster A and B) can be found in low density mangrove area (zone IIa and IIb, Map 7, Appendix 6).

The classification of water quality at stations resulted in 7 clusters. The main differentiating factors of water quality between 2 study areas are salinity and TSS. Ca Mau has higher salinity and TSS levels than Tra vinh.

Water quality in clusters along the main channels in Ca Mau and Tra Vinh is less suitable to shrimp farming due to high level of TSS and low levels of primary productivity. We also can find the best local yields in these main channels are lower than in other parts. The influence of TSS to water ecosystem is obstruction of light penetration. Primary production can't be produced and consequently affect shrimp yield in extensive farming system. Such a situation can also be found in cluster G (C07 and C12).

There are just one and two memberships in cluster C and G respectively. The analysis of next survey farm data should confirm the effect of the environment by surveying more farms in these locations.

5.3 Classification of shrimp farms

The classification of shrimp farms resulted in six different clusters. These types are characterized by variables as shown in Table 5.4.

Table 5.4 : Characteristics of shrimp farms in the study area identified by cluster analysis

Characteristics	Clus 1	Clus 2	Clus 3	Clus 4	Clus 5	Clus 6
PL age (day)	15.7	16.6	15.3	15.1	20	27
Pond age (yr)	6.8	7.0	7.2	16.6	7	5.3
Pond area (ha)	1.4	1.2	1.1	1.0	9.5	0.3
Pond depth (m)	0.7	1.1	0.8	0.8	0.9	1.0
SD (PL/m2)	5	4.4	20.4	7	0.9	5
Mean yield (kg/ha) (std.)	220.0 (268.3)	178.3 (207.0)	554.4 (394.6)	100.3 (203.8)	10.0 (14.1)	450.0 (247.5)
Eff. Index (kg/1000PL) (std.)	5.92 (6.17)	5.51 (6.45)	2.71 (2.02)	1.44 (1.41)	5.71 (0)	4.33 (0.94)
Size (% of all farms)	53 (43.8%)	39 (32.2%)	14 (11.6%)	9 (7.4%)	2 (1.6%)	4 (3.3%)
Ca Mau	24	9	12	8	1	1
Tra Vinh	29	30	2	1	1	3
No. of farm having best. yield (per station) (% of farms in cluster)	15 28.3%	5 12.8%	9 64.3%	1 11.1%	-	1

<u>Cluster 1</u> : Extensive with pond area 1.4 ha and stocking density 5 PL/m^2.
<u>Cluster 2</u> : Extensive with pond area 1.2 ha, stocking density 4.4 PL/m^2. and the highest pond depth 1.1 m.
<u>Cluster 3</u> : Pond area is close to cluster 2 and 3 but stocking density is the highest with 20.4 PL/m^2.
<u>Cluster 4</u> : Extensive system, shrimp farms in this cluster were distinguished by pond age (16.6 years), the oldest pond among clusters.
<u>Cluster 5</u> : Extensive system with very large pond area 9.5 ha and low stocking density about 1 PL/m^2.
<u>Cluster 6</u> : Shrimp farms in this cluster can be identified in extensive+ shrimp farming system with small pond area 0.3 ha and high stocking density 5 PL/m^2.

- The classification of shrimp farms was influenced by stocking density, pond area, pond age and PL age. Pond depth did not have a strong effect on clustering.

- There are 2 and 4 shrimp farms in Cluster 5 and 6 respectively. These two clusters were distinguished from the others because of PL age (20 and 27 days) and pond area (9.5 and 0.3 ha), however, they are little representative.
- Almost every cluster can be identified in extensive shrimp farming system because of the large pond area (more than 1 ha).
- Every groups of farm is distributed in both study area. However, cluster 3 is dominant in Ca Mau and cluster 2 in Tra Vinh.
- Average shrimp yield in all clusters have standard deviations higher than means except cluster 3.
- Nine shrimp farms in cluster 3 (64.3 %) are the best yield farms in each station, eight farms in Ca Mau and one farm in Tra Vinh (Map 8 and 9, Appendix 6). This cluster was identified by a very high of stocking density (20.4 PL/m^2) but the other parameters were not different from the other groups. This result can explain the behaviour of shrimp farmers mostly in Ca Mau. They try to improve shrimp yield by increasing stocking density but they do not change their techniques. It is clearly reported in literature that pond design mostly pond size and pond depth are leading function of increasing yield (Johnston, 2000) which is not the case here. In spite of this, 9 among these 14 farms achieve better yield than their neighbours, however with smaller efficiency. This need to be investigated more in depth.

6. Conclusion

Following reports of unstable and unevenly distributed yields of shrimp rearing throughout the two coastal provinces in the Mekong delta, this study attempted to give an account of some specific features of this activity, based on ecological and farming practise data. These data were collected at 35 stations and 121 farms in their vicinities between March 2001 and March 2002. The assumption was made that they could be jointly analysed statistically, i.e. that some relations existed between them.

Environmental analysis showed that this ecosystem cannot be characterized only with salinity, organic matter and suspended particulate. A group of variables featuring primary productivity (which develops better in more confined zones) clearly accounts for better yields. Also, land cover maps have revealed that mangrove seems 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. Soils data collected by the project, not yet available, should help refine the land cover zonation.

In the Mekong delta, production systems can be summarized at the most in two systems types usually referred to as extensive and "extensive plus". However even these two types are mostly indistinct. It was therefore difficult to obtain a reliable classification. One clear group came up, featuring much higher stocking densities than others. A number of farms among this group do have better yields than their neighbours, but at which cost when their technical efficiency is shown to be low?

Crossing mapping results between the two classifications remained difficult, however joint maps help bring up new tracks of investigation. It would be interesting to a) look at "outliers", i.e. farms that achieve unexpected bad yields in view of their ecological environment, b) concerning "best local yield" look specifically at farms that really stick out against their neighbours within groups at stations. Efficiency should also be examined at a later stage : provided farmers do not produce much from wild stock, it is a more effective measurement than yield. Besides, another farm survey has been carried out last August and the data are expected to be of higher reliability, opening new prospects.

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Appendix 1

Multivariate Analysis Technique

Multivariate statistical analysis has been developed to deal with situations in which there are two or more variables that we would like to analysis simultaneously. They can be divided in two broad categories,

1. Regression Type

The value of a single response variable is assumed to be a function of a set of predictor variables i.e. in a generalised format $y = f(x)$. These methods are generally classed as regression analysis.

2. Ordination Type

The objective of this method is dimensional data reduction. Two general categories of methods have been recognised :

2.1 Geometrical or projection methods, such as principal component analysis, that reduce the number of variables by creating a set of new variables that are linear combinations of the existing p variables. Most of these methods are based on eigenvalue analysis methods.

The main aim of the geometrical methods is compression of the variables. The reason for this approach is that studies often collect data for many variables. A large number of variables is difficult to process and assimilate. Many of the variables will be correlated. Consequently it may be possible to combine them into a small number of groups. A variety of methods have been employed to obtain these new variables, mainly Principal Components Analysis (PCA), Correspondence Analysis, Canonical Correspondence Analysis. Geometrical method applied in this study is PCA

Principle Component Analysis (PCA)

Objective :

PCA is the method to reduce the complexity of multivariate data by transforming the data into the principle components space. PCA is the unsupervised classification. Look at data as the vector. One principle component is composed by different coefficient of vector. Number of dimension is equal number of variables.

Interpretation :

There are many criteria for interpretation the result.

- 90% criterion by choosing the first *n* component explaining the original variable.
- Kaiser's criterion: selecting the component that has eigenvalues (component's variance or stdv^2) > 1

2.2 Classification methods, such as cluster analysis, which reduce the number of rows from n to m by placing individuals into m clusters on the basis of similarities in their variable scores.

Clustering and partitioning methods are used to group cases on the basis of their similarity over a range of variables. The main examples of these techniques come under the general heading of cluster analysis. Many clustering algorithms are available.

Cluster algorithm is the rule which govern how distance is measured between clusters. It differ with respect to the method used to measure similarities (or dissimilarities) and the points between which distances are measured.

Thus, although clustering algorithms are objective, there is scope for subjectivity in the selection of an algorithm. The main clustering algorithms are divided in two types :

- Hierarchical classification : divided be divisive or agglomeration. A divisive method begins with all cases in one cluster. This cluster is gradually broken down into smaller and smaller clusters. Agglomeration starts with each object forming a separate group and in which objects or groups close to one another are successively merged.
- Iterative relocation start with an initial classification and attempts to improve it iteratively by moving objects from one group to another.

The most common clustering is polythetic agglomerative, i.e. a series of increasingly larger clusters are formed by the fusion of smaller clusters on the basis of more than one variable. A problem with the hierarchical approach is that they are computer-intensive and large data sets may be difficult to analyse. A less computer intensive approach is the nonhierarchical k means or iterative relocation algorithm. Each case is initially placed in one of k clusters, cases are then moved between clusters if it minimises the differences between cases within a cluster.

Appendix 2

Confinement index

Water circulation and discharge can affect water quality. In the area where there is a weak discharge, particulate matter can be decanted. Light can penetrate water consequently with the addition of photosynthesis activity.

A confinement index was used in water quality analysis in order to prove that can it be use as an index for assessment environmental quality for shrimp farming ?

Confinement index is an index to measure how the water was confined in the given place connecting to the sea ex. lake, estuary, semi-enclosed bay.

Water circulation is a function of river cross-section and slope and the tidal amplitude which is the engine of water flow. There is only a hydrodynamic model is capable of giving a good account of water flow, specifically of residual flow, i.e. the ability of water particle to be renewed.

Such a model was made in Ca Mau, yielding residual flow at 8 Gambas stations. To extend this result to other station including in Tra Vinh ones, a "proxy" formula was used, expected to approach residual flows as discriminating factors between stations. Distance to sea and river cross-sections were measured for each station and a non-dimensional "confinement index" computed as:

$$C = D / \mathrm{sqrt}(S)$$

D : distance to the sea (km)
S : cross section (m2)

The justification for using this proxy lies in the acceptable correlation on $r^2 = 0.84$ shown with residual flows. For place with no modelling results available given its high correlation with primary productivity, could be the confinement index used if no specific water quality measurements were possible.

Confinement index at station in Ca Mau province

Station	Point to sea	Distance to sea (m)	Cross section (m^2)	Confine index	Residual flow (m^3/s)
C02	C01	8,700	3,456	0.15	1441
C03	C01	12,400	470	0.57	214
C04	C01	16,400	89	1.74	
C05	C01	26,200	4,926	0.37	1266
C06	C01	30,500	266	1.87	38
C07	C01	34,800	188	2.54	
C08	C01	57,316	6,501	0.71	
C09	C01	50,802	6,867	0.61	815
C10	C01	39,800	6,415	0.50	1097
C11	C01	42,800	459	2.00	18
C12	Bay Hap mouth	19,800	291	1.16	8
C13	Bay Hap mouth	27,500	419	1.34	
C14	Bay Hap mouth	32,200	255	2.02	
C15	Bay Hap mouth	38,500	354	2.05	46

Confinement index at station in Tra Vinh

Station	Point to sea	Distance to sea (m)	cross section (m2)	confinement index
T02	Dinh An	7,290	2,112	0.16
T03	Dinh An	12,700	1,709	0.31
T04	Dinh An	17,230	1,608	0.43
T05	Dinh An	19,150	1,175	0.56
T06	Dinh An	21,250	914	0.70
T07	Dinh An	21,240	342	1.15
T08	Dinh An	23,360	241	1.50
T09	Dinh An	24,880	159	1.97
T10	Dinh An	26,250	106	2.55
T11	Dinh An	28,030	554	1.19
T12	Lang Nuoc	720	5,094	0.01
T13	Lang Nuoc	4,350	3,499	0.07
T14	Lang Nuoc	9,430	2,448	0.19
T15	Lang Nuoc	13,200	2,590	0.26
T16	Lang Nuoc	15,100	139	1.28
T17	Lang Nuoc	16,500	83	1.81
T18	Lang Nuoc	19,100	27	3.68
T19	Lang Nuoc	18,750	72	2.21

Appendix 3

Database tables

Explanation of the codes and some abbreviations used in the database tables.

Table Station

Code	Abbreviations
code_station	Identifier code
Lat	Latitude of station location
Long	Longitude of station location
tidal_range	Tidal amplitude at station (m)
Cross_section	Cross section at station (m2)
Distance to sea	The distance from stations to the point to sea (m)
Poin to sea	Point at river flow to the sea
Confine_index	Confinement index
G_wquality	Group of water quality stations in dry season

Table Farm

Code	Abbreviations
Code_farm	Identifier code
Code_station	
Code_village	Code of village
Nb of sluice	Number of sluices in farm
Nb of pond	Number of ponds in farm
Pond age	Age of shrimp pond
Pond depth	Depth of shrimp pond
Code_treatment	Code of shrimp pond treatment
Code_soil origin	Code of the soil origin of shrimp pond
Code_Plsource	Code of post larvae source
PL age	Age of post larvae
Code_acclimate	Code of post larvae acclimatization
Code_water renewal	Code of water renewal to shrimp pond
Water exchange	Period of water exchange to shrimp pond
G_fpractice	Shrimp farm groups (result from analysis)

Table Farm operation

Code	Abbreviations
Idf	Identifier code
Code_survey	Month and year when doing the water sample survey
Labour cost	Labour cost per crop
Depreciation	Depreciation cost per crop
Total cost	Total cost per crop
Profit rate	The profit rate per crop
Farm area	Area of shrimp farm
Yield	Shrimp production per area
SD	Stocking density

Table Pond treatment

Code	Abbreviations
Code_treatment	Identifier code
Pond_treatment	The process for treatment shrimp pond before starting shrimp crop

Table Pond origin

Code	Abbreviations
Code_soil origin	Identifier code
Pond soil origin	The origin of soil before converting to operate shrimp farm

Table PL source

Code	Abbreviations
Code_PLsource	Identifier code
Source of PL	The area that the shrimp farmers buy post larvae

Table PL acclimatization

Code	Abbreviations
Code_acclimate	Identifier code
Time	Time for acclimate post larvae before dropping to shrimp pond

Table Water renewal

Code	Abbreviations
Code_renewal	Identifier code
Water renewal	The way to inlet water to shrimp pond

Table Survey

Code	Abbreviations
Code_survey	Identifier code
Time survey	Timing of data surveying
Code_season	Code of season of data surveying

Table Season

Code	Abbreviations
Code_season	Identifier code
Season	Dry or rainy season

Table Village

Code	Abbreviations
Code_village	Identifier code
Village	Village name that the farm belong to

Table District

Code	Abbreviations
Code_district	Identifier code
District	district name

Table Province

Code	Abbreviations
Code_province	Identifier code
Province	province name s

Table Water sample

Code	Abbreviations
IDw	Identifier code
Code_station	Number of station
Date	Date of water sample
Time	Time of water sample
Code_survey	Month and year of water sample surveying
Depth	Depth at water sampling stations (m)
Level	Depth of water sample (m)
Diss_oxy	Dissolved oxygen
Temp	Water temperature
Salinity	Salinity
PH	
Turbidity	
TSS	Total suspended solid
Org_mat	Organic matter
OM in TSS	The ratio of organic matter over TSS
N_part	Nitrogen particulate
C_part	Organic carbon particulate
C/N	The ratio of Organic carbon particulate over Nitrogen particulate
Pico_cyano	Pico-cyano bacteria
Micro_cyano	Micro-cyano bacteria
Pico_eucar	Pico-eucaryote bacteria
Hetero_bact	Heterotrophic bacteria
Chlott_IRD	Chlorophyll total measured by IRD
Prim_prod(IRD)	Primary productivity measured by IRD
AssimNo	Assimilation number
Chlott_ION	Chlorophyll total measured by ION (Vietnam)
P_gross	Gross primary productivity
P_net	Net primary productivity
P_resp	Respiratory productivity
NH3-4	Ammonia
NO2	Nitrite
NO3	Nitrate
PO4	Phosphate
SiO2	Silicate
BOD5	Biochemical Oxygen Demand (5 days)
COD	Chemical Oxygen Demand
Vibrio	Amout of vibrio in water
SRB	Sulphate reducing bacteria

Appendix 4

Shrimp yield data at water quality stations

Average shrimp yield at water quality stations (* Nineteen station out of thirty-one, the standard deviation is higher than the mean.)

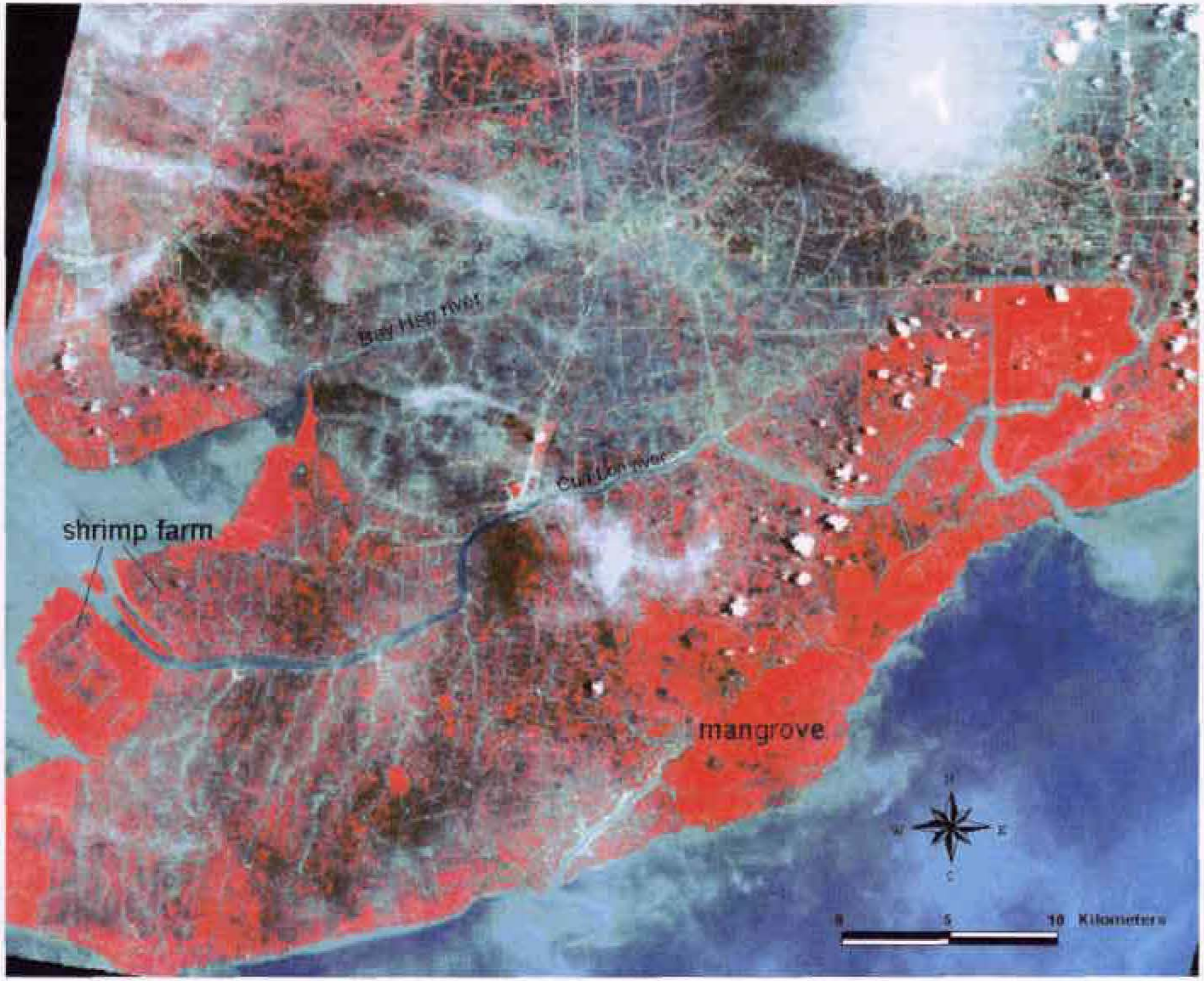
Station	Avg. Shrimp Yield (kg/ha)	Std.
C02	25.00	43.30*
C03	132.40	179.82*
C04	97.60	102.59*
C05	60.74	68.19*
C06	274.17	412.63*
C07	66.52	90.00*
C08	53.95	77.41*
C09	76.88	116.43*
C10	137.38	220.39*
C11	397.00	611.77*
C12	103.21	136.88*
C13	634.58	512.46
C14	282.92	293.77*
C15	192.20	209.93*
T02	229.52	250.70*
T03	144.44	38.49
T04	158.04	185.54*
T05	378.10	347.66
T06	114.38	95.58
T07	432.13	268.87
T08	266.67	251.66
T09	226.46	244.71*
T10	448.54	439.90
T11	495.00	247.13
T13	129.11	168.84*
T14	102.56	177.65*
T15	77.50	96.74*
T16	507.50	442.05
T17	365.45	330.07
T19	349.00	295.54
T20	354.93	253.22

Appendix 5

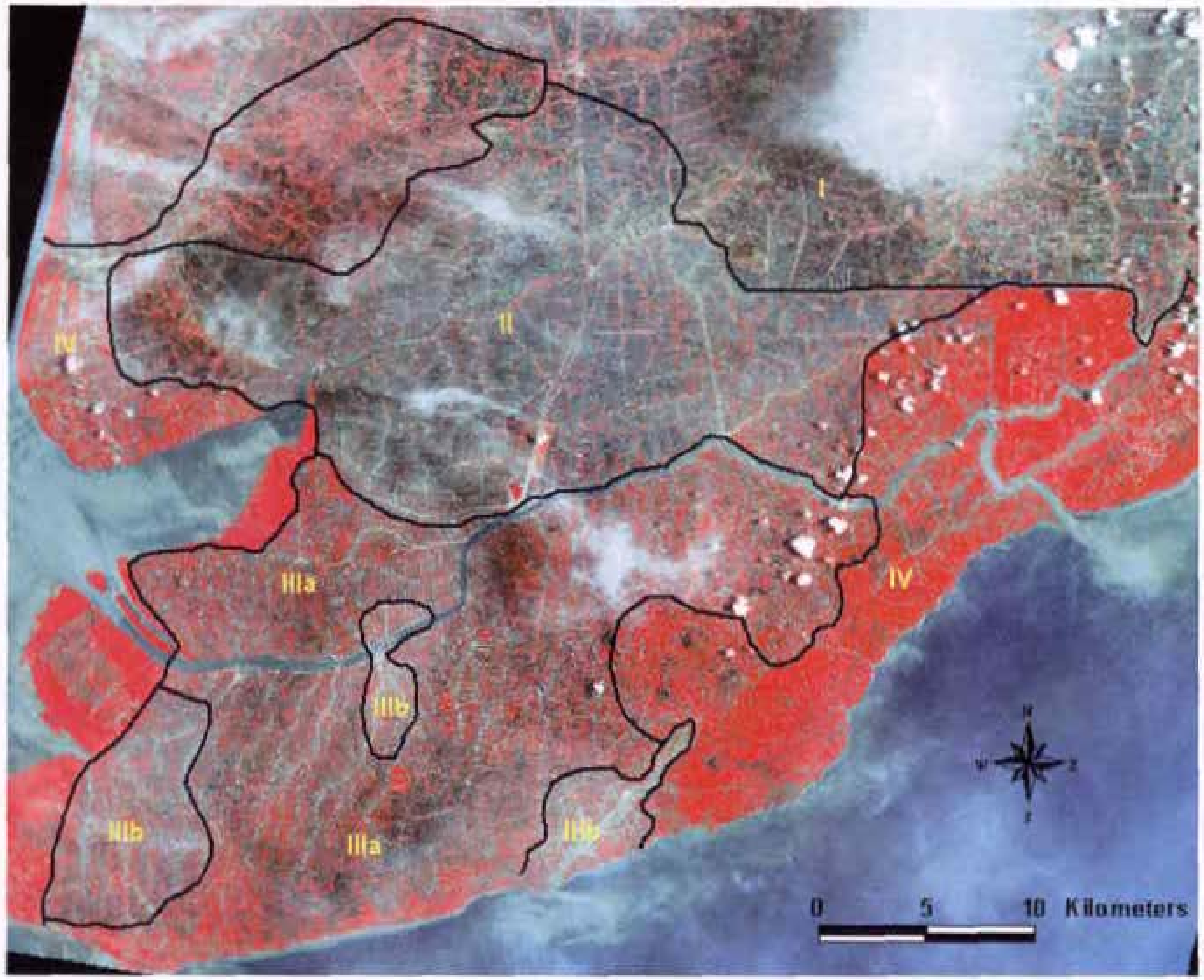
Land use maps and satellite images

Map A	A color composite (band 3,2,1 : R,G,B) in Ca Mau
Map B	A simplified synthesis of land use classes in Ca Mau
Map C	A simplified synthesis of land use classes in Tra Vinh

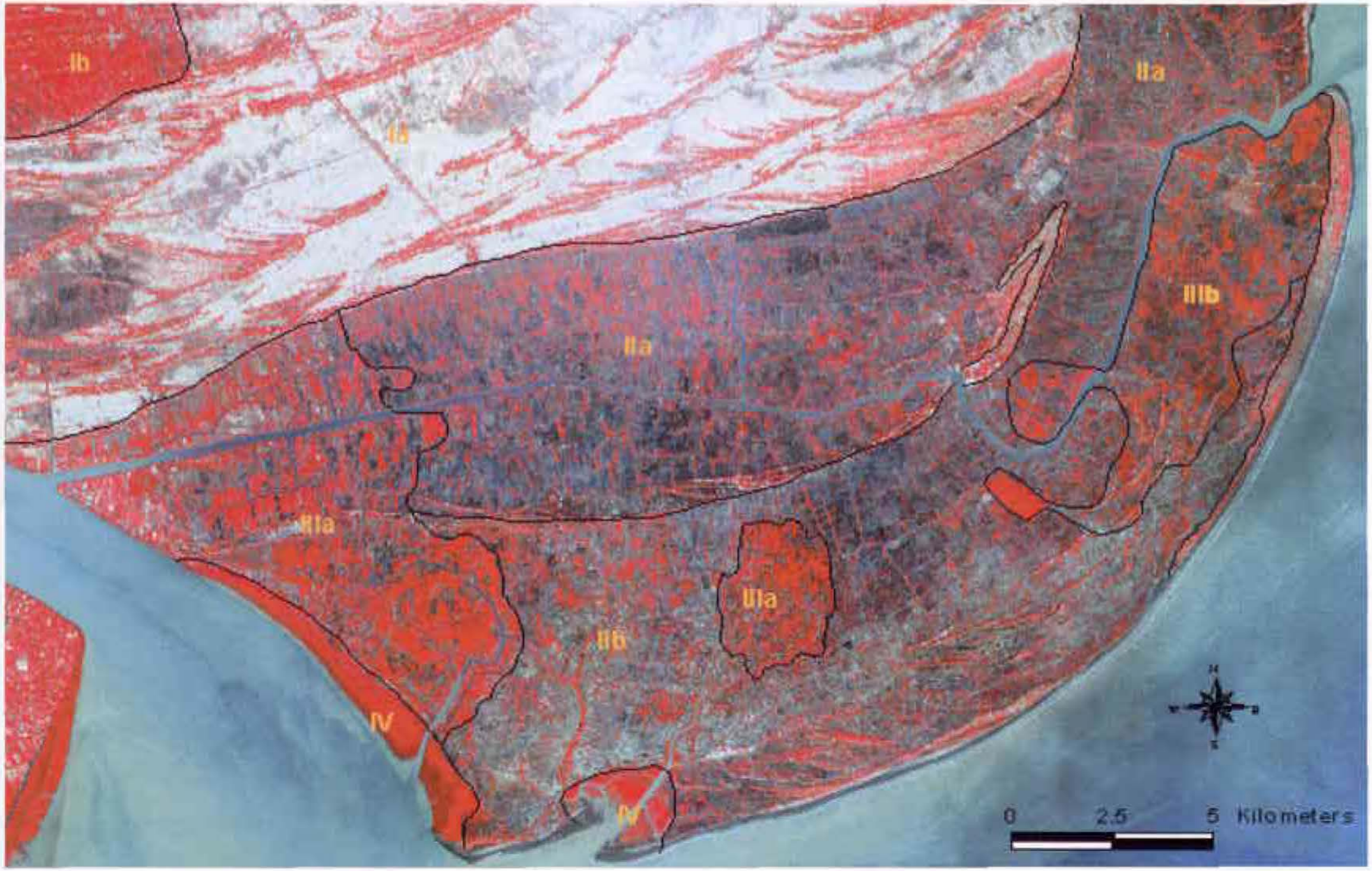
Map A : Spot4 color composite (band 3,2,1 : RGB) in Ca Mau



Map B : A simplified systhesis of land use classes in Ca Mau



Map C : A simplified systhesis of land use classes in Tra Vinh



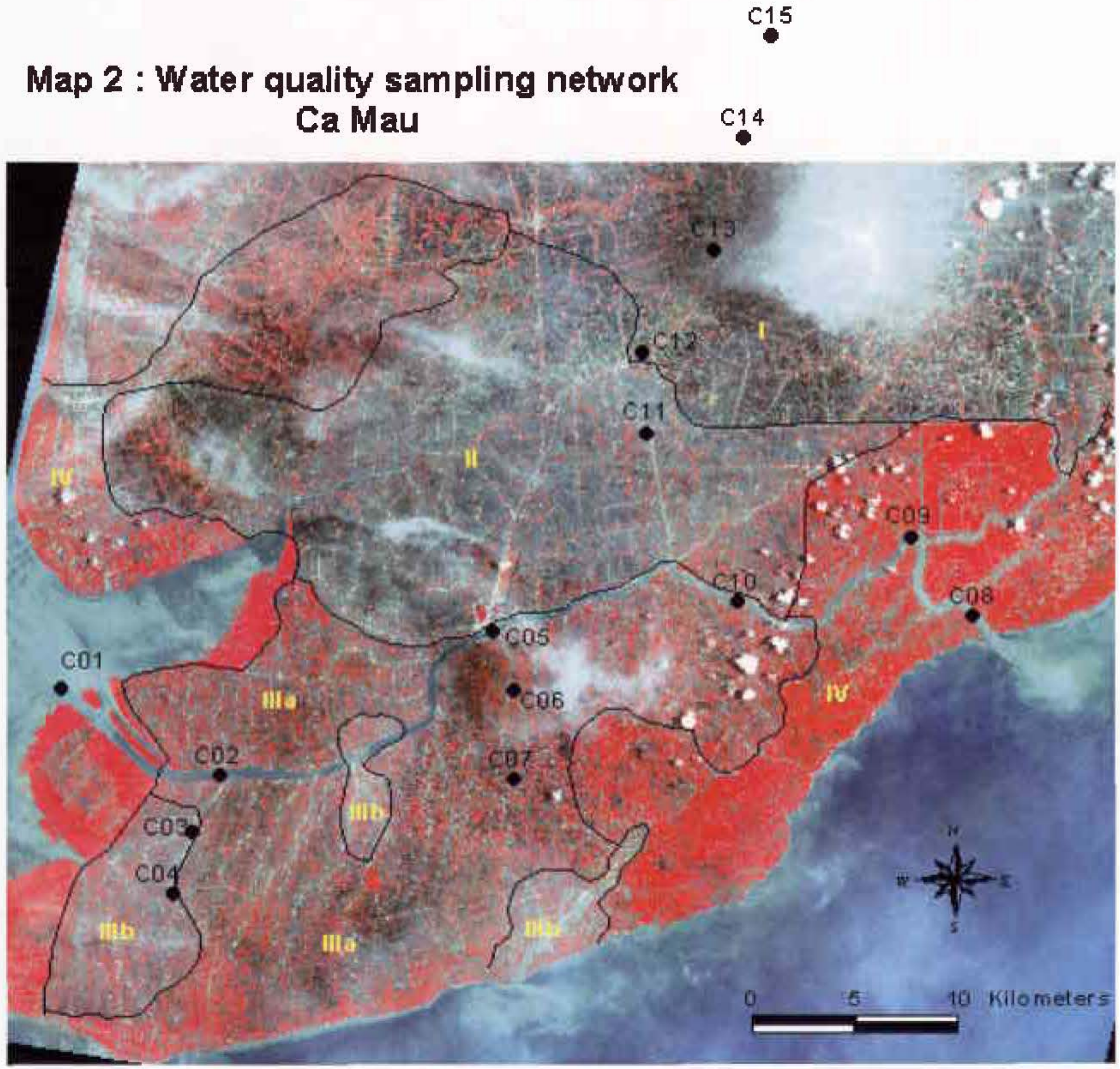
Appendix 6

Study areas and result maps

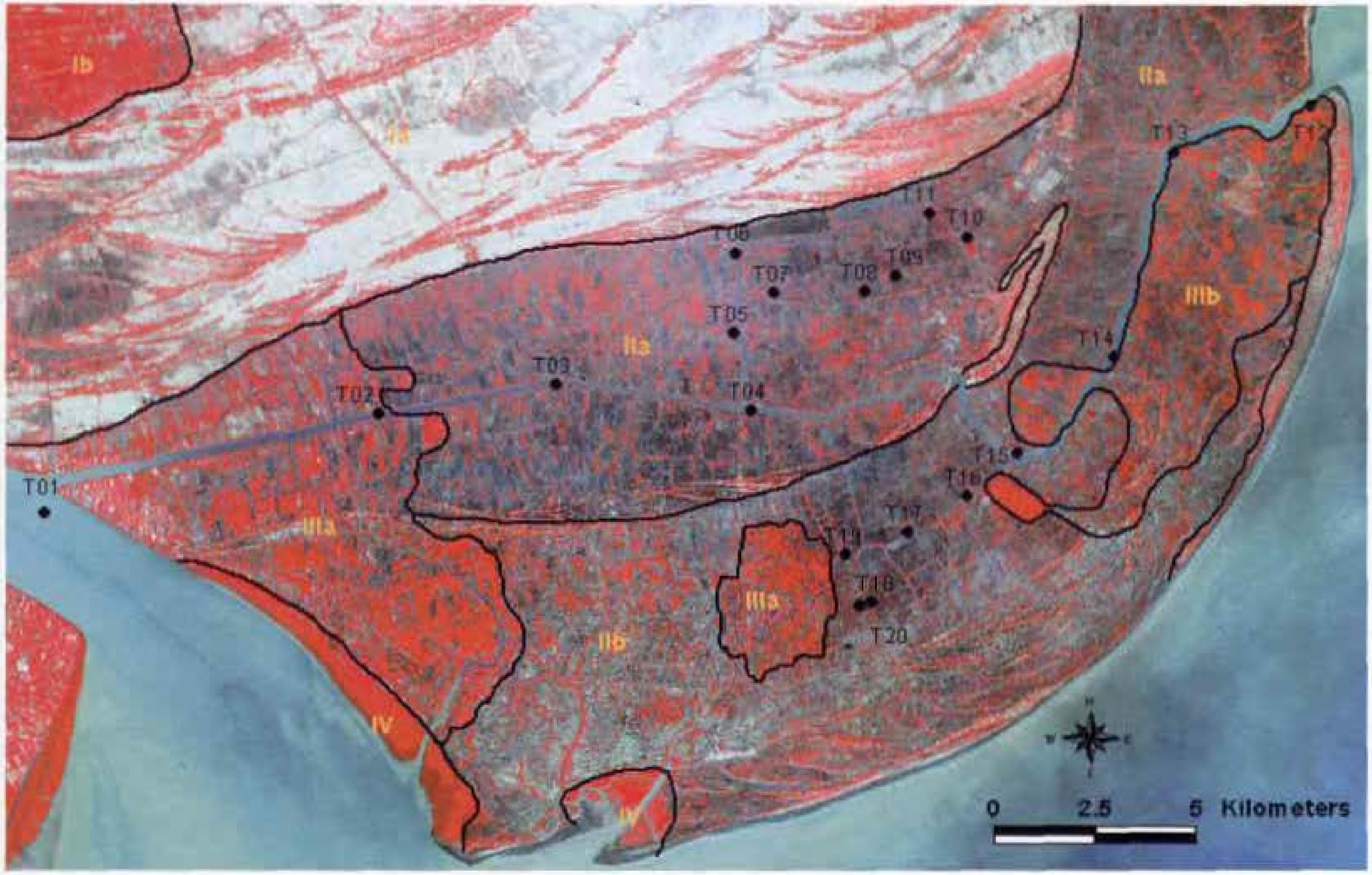
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. These maps may be freely distributed. If more current information is available, please update the maps and return them to ReliefWeb for posting.

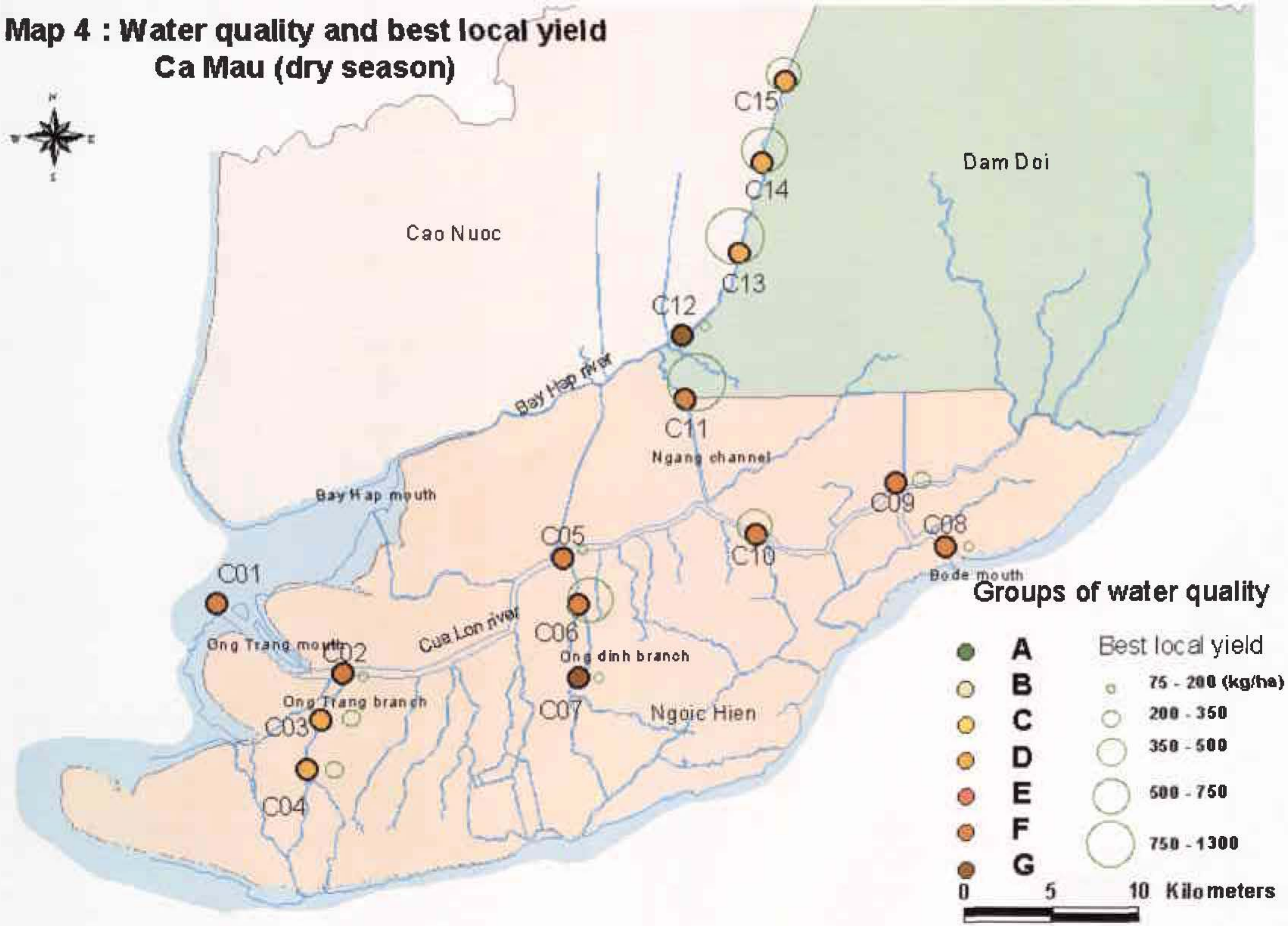
Map 1 : Location of the study areas in the Mekong delta

Map 2 : Water quality sampling network
Ca Mau



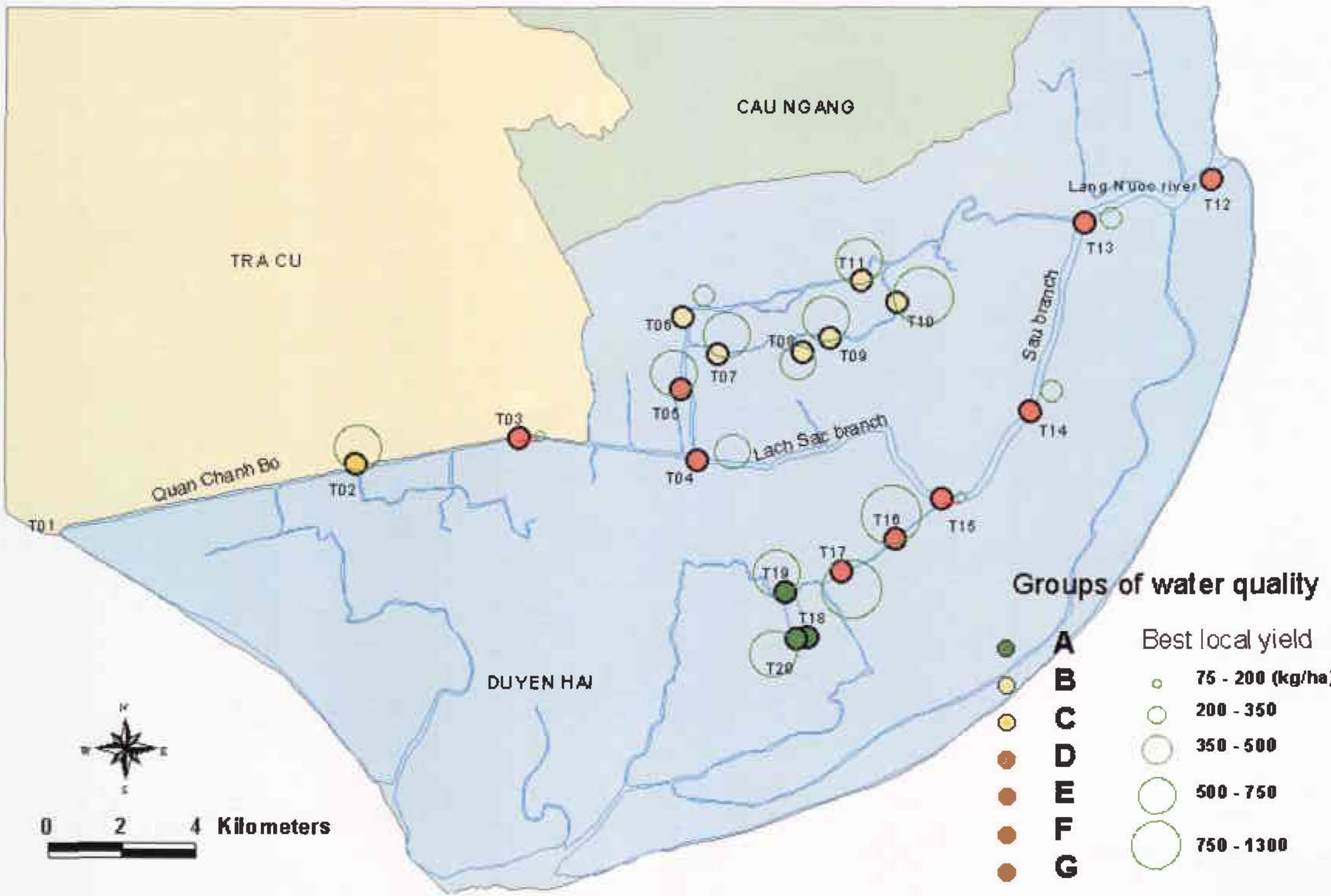
Map 3 : Water quality sampling network - Tra Vinh



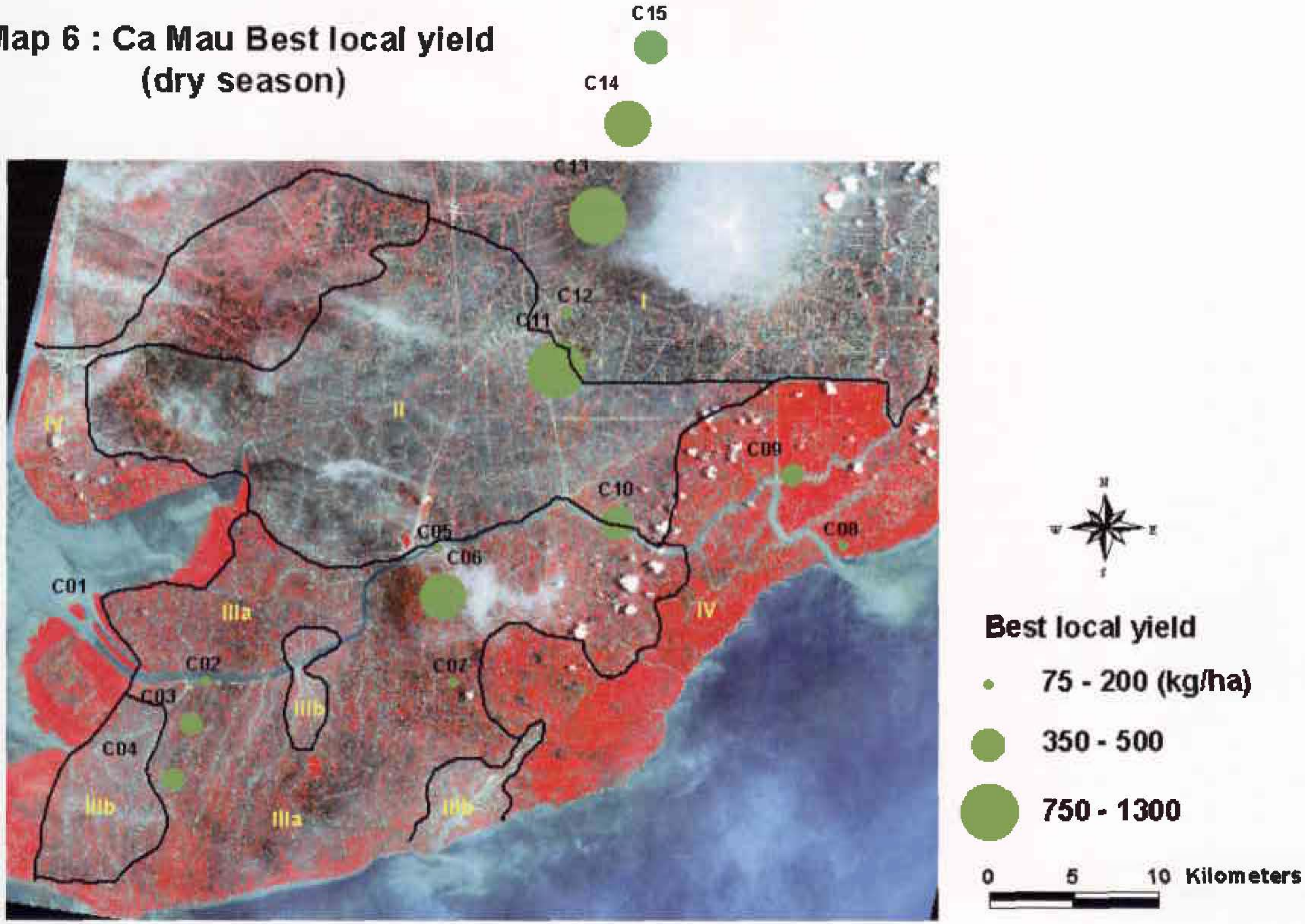


Map 4 : Water quality and best local yield
Ca Mau (dry season)
Cao Nuoc
Dam Doi
C15
C14
C13
C12
Bay Hap river
C11
Ngang channel
Bay Hap mouth
C09
C08
C05
C10
Bode mouth
C01
C06
Cua Lon river
Ong Trang mouth
C02
Ong dinh branch
Ong Trang branch
C03
C07
Ngoic Hien
C04
Groups of water quality
A
B
C
D
E
F
G
Best local yield
75 - 200 (kg/ha)
200 - 350
350 - 500
500 - 750
750 - 1300
0
5
10 Kilometers

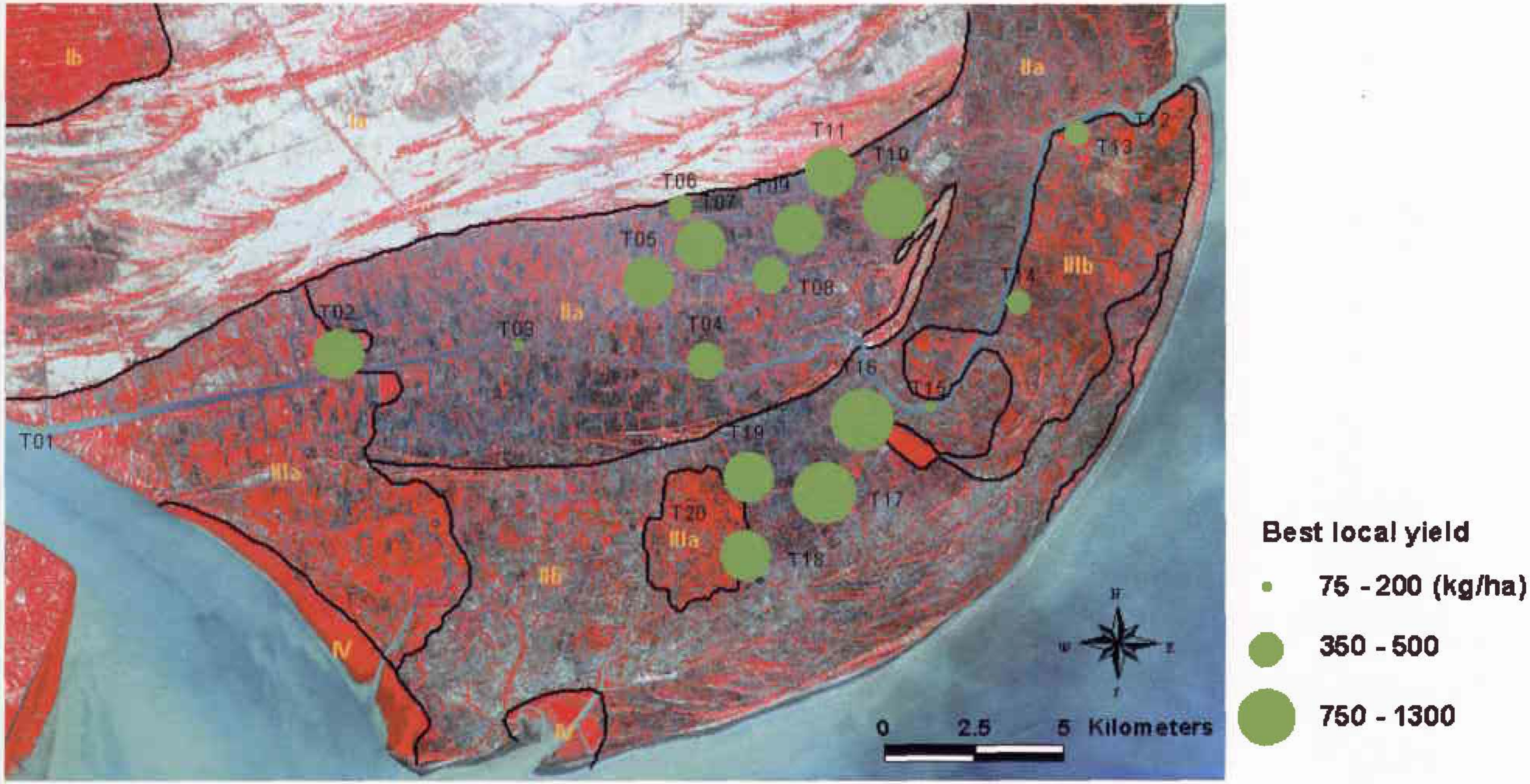
Map 5 : Water quality and best local yield Tra Vinh (dry season)



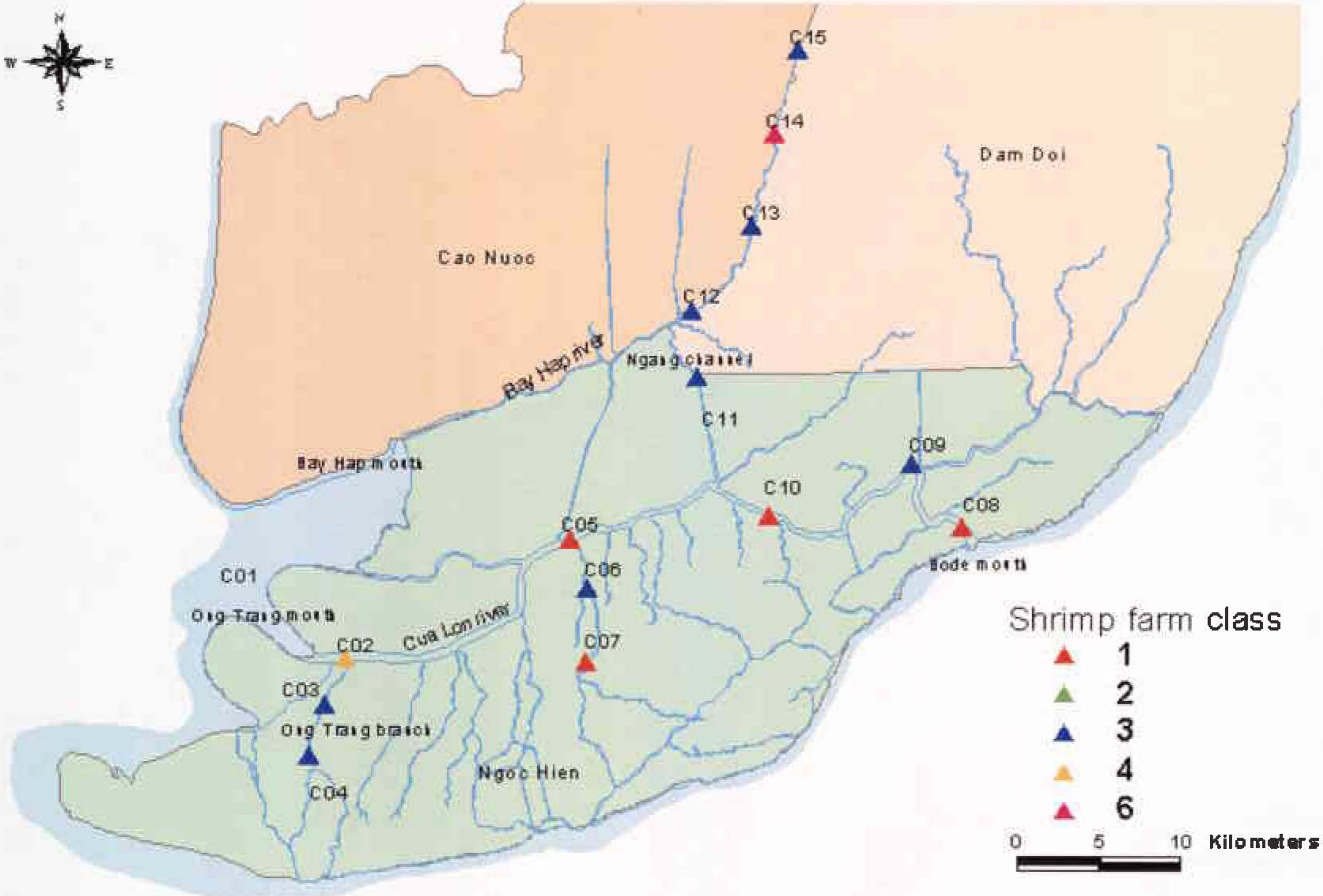
Map 6 : Ca Mau Best local yield (dry season)



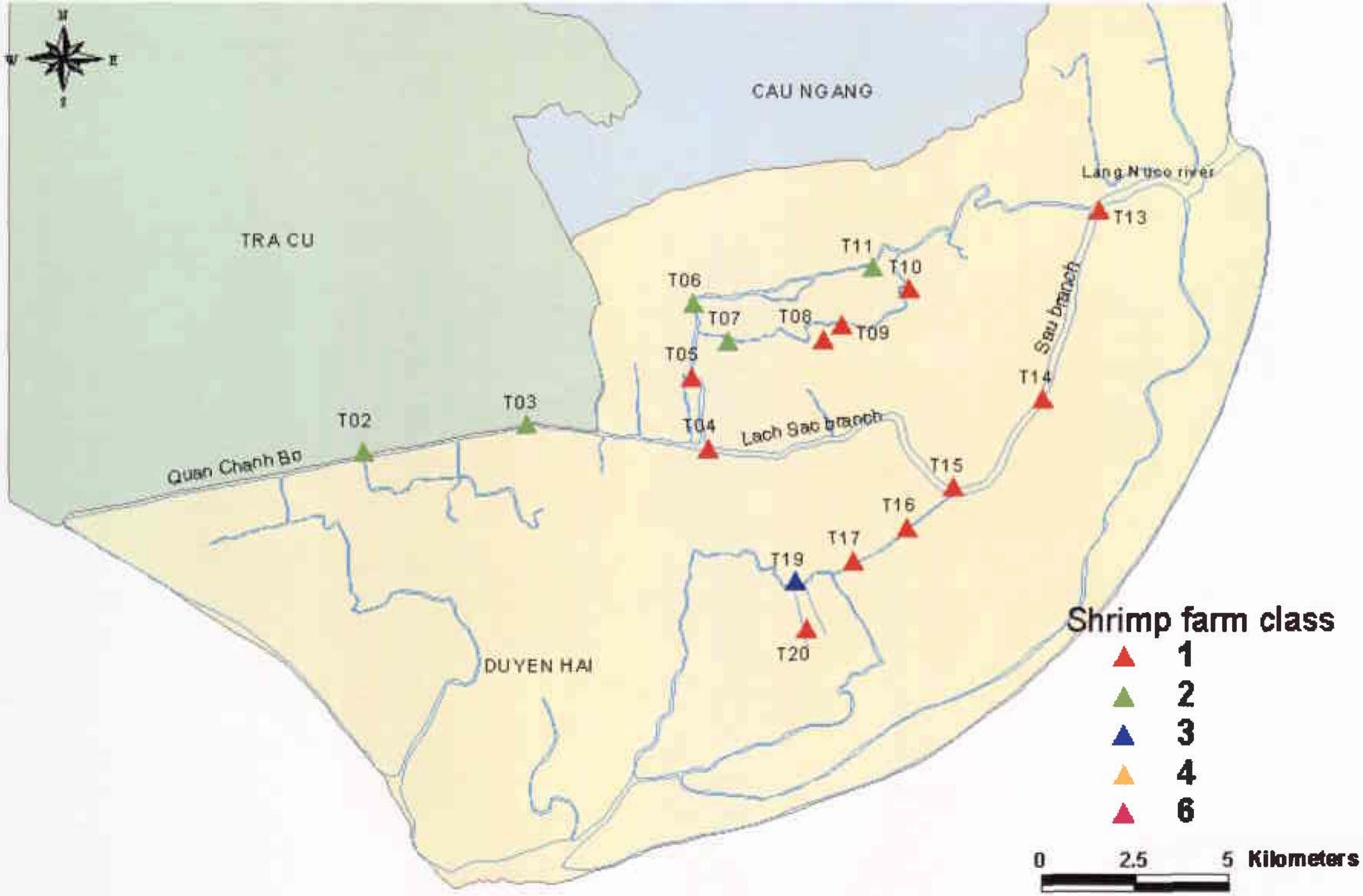
Map 7 : Tra Vinh Best local yield (dry season)



Map 8 : Class belonging of best local yield Ca Mau (dry season)



Map 9 : Class belonging of best local yield Tra Vinh (dry season)



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