Synthesis through integrated modelling

Quantifying carrying capacity and predicting impacts on the coastal ecosystem

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Contents

1. Introduction
2. Ecosystem approach
3. Toward quantifiable ecosystem state
4. Quantification of ecosystem state
    4.1. Problem scoping: identification of drivers and pressure
    4.2. Definition of indicators and standards for ecosystem state
    4.3. Quantification of ecosystem state using integrated modelling approach
    4.4. Run off and river discharges: Water balance model STREAM
    4.5. Water circulation and water quality, 2D lagoon model
5. Advise to management level
6. Conclusions
7. References, PDF reports and Websites

Summary

One of the main aims of the Vietnam-Netherlands Integrated Coastal Zone Management and the Coastal Cooperative Programme in Thua Thien Hue was to provide the province with tools, to strengthen the quality of the decision-making process for the management of the Hue lagoon area and its surroundings. The TTHue Lagoon is the largest lagoon of SE Asia and provides a livelihood for more than one hundred thousand families.
Training was a fundamental part of the projects. The following actions are urgently needed:

- Physical state - *tools are needed to improve understanding of hydrology, hydrodynamics and sediment transport;*
- Water quality and pollution - *Any intensification of activities in the future should be carefully controlled and limited;*
- Ecology - *Fishing intensity should be reduced and valuable, shallow habitats should be protected and partly restored;*
- Governance: *More ICZM expertise is needed to facilitate and continue the ICZM process providing sustainable solutions.*

The Vietnamese – Netherlands Coastal Cooperative Programme organised surveys to quantify the state of the ecosystem, including the impact of human activity and the carrying capacity of the Lagoon. The results, together with supporting coastal hydraulic and water balance models of the TTHue river basins, formed the basis for the development of an integrated river-lagoon-sea model. This model was interactively developed during one of the hands-on training workshop in Hue. One of the main conclusions was that the strong growth in aquaculture poses a serious threat to the functioning of lagoon itself. The rapid increase in aquaculture waste in the near future will add a large amount of contaminants that will cause international water quality standards to be exceeded.
High-level provincial authorities welcomed the results of the workshop and the series of recommendations. One of these was the creation of international and inter-university cooperation in the field of integrated ecosystem monitoring, modelling and policy preparation. The integrated ecosystem approach will help the application of good governance for the sustainable use of resources in the coastal zone, ensuring inter-sectoral cooperation and optimal institutional arrangements.

1. Introduction

The implementation of ICZM relies on quality advice and on a high level of understanding of the interrelated nature of the local coastal system. This requires a thorough understanding of the functioning of the local ecosystem and of the impact of human activities on it. For this, a comprehensive and coherent system of management practice, experts, tools and data collection should be in place. Although this is well understood, successful implementation in governance depends on availability of local expertise and effective financial, organisational and governmental control of the process. In Thua Thien Hue Province this approach involved:

- Development of an effective information base and
- Training experts in the implementation of ICZM by means of problem solving in relevant case studies.

An expert training programme was organised and organisational structures were strengthened. Evaluation of the programme proved the relevance of training and tools for improving coastal management capabilities, but also highlighted the deficiency of expertise and organisational capacity in applying ICZM in practice. In this chapter, we show that a bottom-up analysis of the state of the ecosystem using the DPSIR frame (Driving forces, Pressure, State, Impact and Response framework, see EEA website) , is a powerful tool for collating and integrating data when developing the knowledge base. We show that data-integration by means of mathematical models provides the predictive capability needed by managers. Finally, useful management information can be produced at a high level of integration, which is a requirement for successful ICZM implemented by trained experts and policy makers within effective inter-departmental structures.

The training component of this project uses an analysis of the functioning of the coastal ecosystem in an integrated way. The work was undertaken as a cooperative venture between Netherlands and Vietnamese experts, within the framework of the Vietnam-Netherlands Integrated Coastal Zone Management (VNICZM) project (1999 – 2004) and the Coastal Cooperative Programme (CCP, 2001 - 2006), by jointly implementing model studies and monitoring programmes. This approach proved to be very valuable in integrating dispersed pieces of information into a comprehensive, coherent and illustrative picture of lagoon hydrodynamics and water quality, linking the rivers, lagoons and coastal areas with the sea. Without an integrated approach and predictive modelling, it is impossible to evaluate the impact of infrastructure development and changes in land use on water circulation or on water quality. Therefore, the ability to make sound decisions with respect to zoning and impacts of present and future lagoon uses requires such a model. This predictive capability also allows analysis of possible impacts of changing climate and sea level on the state of the ecosystem and the consequences for economic development.

2. Ecosystem approach

What does the approach encompass?

The ecosystem approach is a practical methodology for integrated and balanced decision-making with respect to management of land, water and living resources. It provides a framework at various levels, including national policymaking and site-level management. The ecosystem approach promotes conservation and the sustainable use of resources in an equitable way. It recognises that humans are an integral component of the ecosystem. The ecosystem approach provides the framework for action under the United Nations Convention on Biological Diversity (see UN-CBD website), adopted at the Earth Summit of Rio de Janeiro in 1992. Vietnam is one of the 100 parties that ratified this convention.

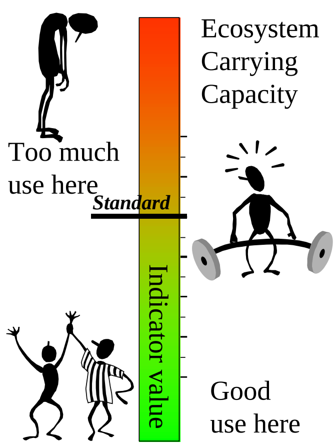
This approach also provides a firm basis for Integrated Coastal Zone Management and it became a practical method for analysing the status of the ecosystem using a set of easily quantifiable indicators for the TTHue lagoon system. This method provides guidance on the sustainable use of resources for a very broad range of socio-economic activities taking place in the coastal zone, that impact on the state of the ecosystem.

What kind of information does the approach require?

The collection of information dealing with resource use, physical, biological, chemical, social and economic characteristics is important to the successful implementation of an ecosystem approach. Information derived from all possible sources has to be integrated into the system and packaged into higher-level information that facilitates communication between stakeholders, planners and decision-makers. A continuous programme of data collation, evaluation and research is needed to identify and bridge strategic gaps in knowledge that are important in addressing the ever changing management challenges. In this project, first steps were made toward collection of information involved setting up an interdepartmental monitoring program, focused on acquiring data on the easily quantifiable indicators in combination with an interdepartmental data sharing and data storage.

3. Toward quantifiable terms of ecosystem state

In view of the complexity of ecosystems, there is a need for a practical method to define measurable and quantifiable terms that express the state of the ecosystem at a given moment in time and to assess the impact of changes in use on the state of the ecosystem. The concept of 'ecosystem carrying capacity' is a useful term, recognised by managers, that helps define the pressures that an ecosystem can 'carry' without 'breaking = degenerating'. At a level of too much pressure, the carrying capacity will be exceeded, as it is unable to accommodate or neutralise the pressures. At this point, there will be a loss of natural resources and reduced potential for socio-economic utilisation.



The point at which the system and its use become unsustainable can be a gradual process with some adverse changes taking place before others. Many examples of this transition exist. In the coastal seas of the Netherlands and Norway, there are increasing occurrences of algae blooms sometimes including toxic species. In stratified nutrient enriched areas depletion of oxygen can occur, a clear sign that the system is 'degenerating'. Changes in natural biodiversity such as species composition and abundance of local fish and bird species can also be indicators of a changing ecosystem. In many systems (such as the lagoons of TT Hue Province) such changes have been observed and may be harbingers of ecosystem damage.

These examples provide clues to the fact that measuring the state of the ecosystem revolves around proper analysis and definition of the problem (Driving forces and Pressures), quantification and valuation of *indicators* that describe the State of the ecosystem with respect to the Impact on the resource and the policy Response (DPSIR).

In brief, the methodology can be broken down into a series of steps:

1. Problem scoping based on identification of drivers and pressures, based on the DPSIR framework and consultation with the local population;
2. Definition of indicators and standards;
3. Quantification of impact of resource use for present and future situations;
4. Assessment of impacts on ecosystem state;
5. Advice on management for sustainable use.

4. Quantification of ecosystem state

4.1 Problem scoping: identification of drivers & pressure

Thua Thien Hue province is located at the latitudes 16°14'- 16°15' North, longitudes 107°02' - 108°11' East. It is 127 km long and 60 km wide on average, with mountains up 1500 m and forests accounting for up to 70% of the natural land. Most of the population lives on the coastal plain, within 25 km of the coast. The main rivers are Huong (Perfume River), Bo, Truoi and O Lau are relatively short rivers and run eastward on steep mountain slopes. Geographically, Thua Thien Hue Province borders Quang Tri Province to the North, Da Nang City to the South, with Laos P.D.R., separated by the Truong Son range, to the West, and the seacoast to the East (Figure 1). Thua Thien Hue Province covers a natural area of 5,009 km^2, and has a population of 1,091,000 in 2002 - accounting for 1.5% of the land and 1.4% of the national population respectively.

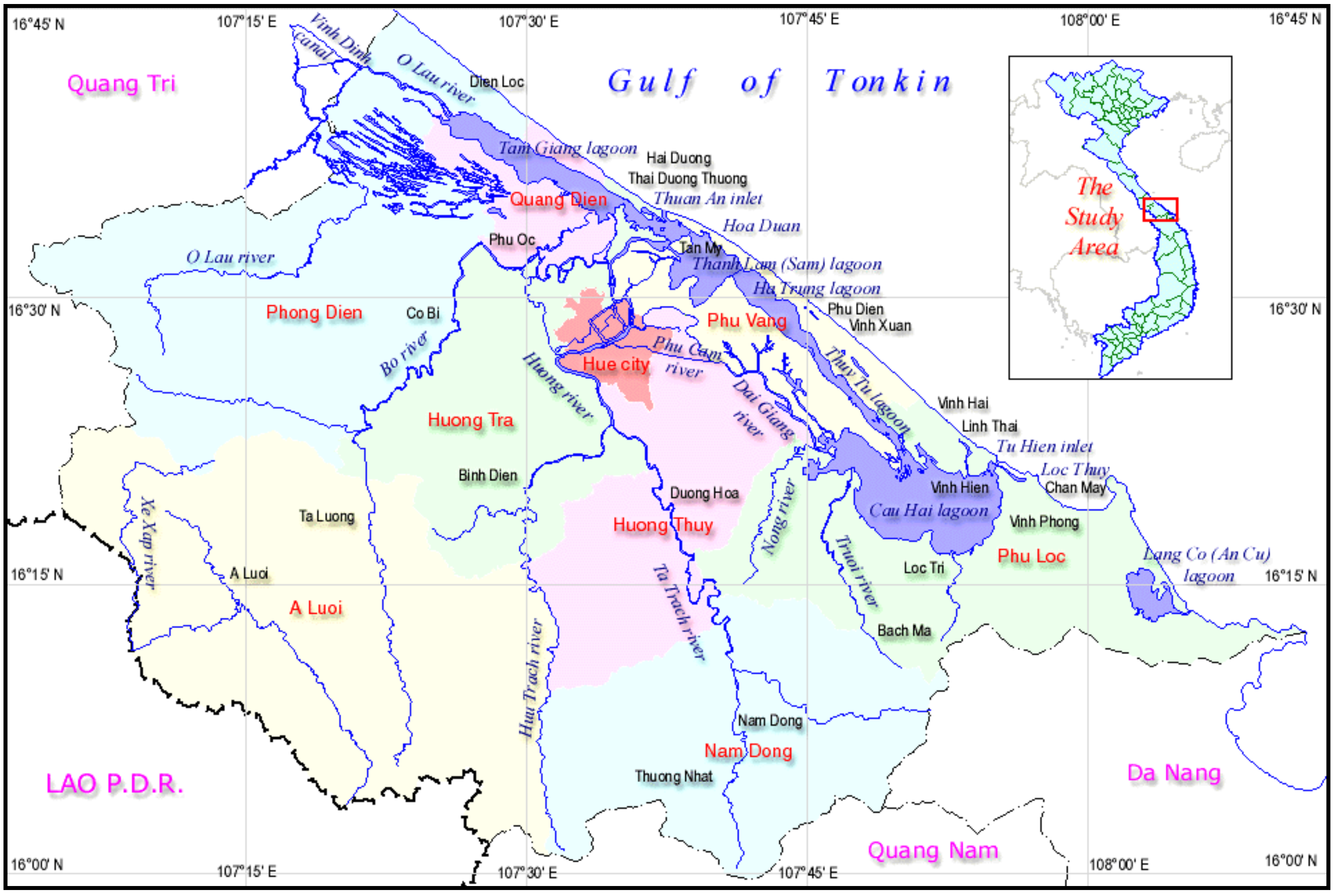


Figure 1: ***Thua Thien-Hue Province****, its Lagoon system: Tam-Giang lagoon in the north with the Thuan An outlet and Ca-Hai lagoon in the south with the Tu Hien outlet, the main rivers and the administrative districts and the boundaries of the capital city Hue. (source: VNICZM project office GIS group)*

The Tam Giang-Cau Hai lagoon system is the biggest lagoon in Southeast Asia, with an area of 220 km^2 and is stretches about 70 km along the coast. The lagoon is strongly influenced by both marine and freshwater inflows. Most rivers in the province flow into it, but only two tidal inlets connect to the sea, making it vulnerable to flooding. The lagoon is a dynamic and sensitive system with a complex set of interacting physical and biological components, controlled by dynamic processes varying in time and space. Extreme flooding occurs during cyclones when abundant rain falls on the adjacent steep mountain slopes. Shifting inlets and coastal erosion have also caused major problems. Hence, it is no surprise that sustainable management of such a complex system is a very difficult task.

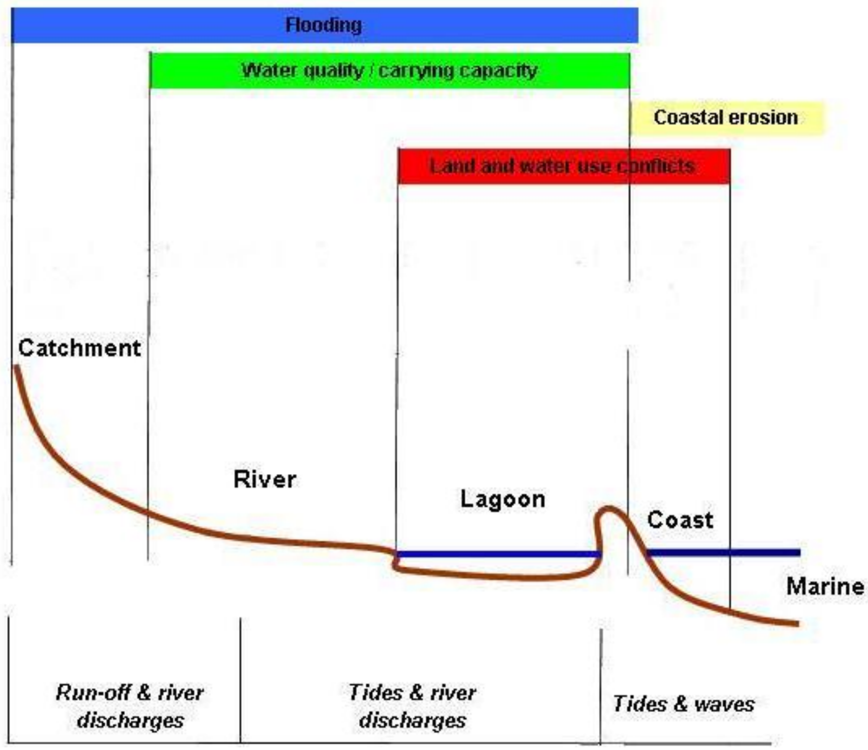


*Figure 2: **Problems and issues** in relation to the water systems of the TTHue Province. (source: CCP 2002)*

Approximately 300,000 inhabitants live around the lagoon in 236 villages and earn their living by directly or indirectly exploiting natural resources. The growing population of TTHue Province is exerting more and more pressure on the lagoon system, through increased agriculture, aquaculture, fishing, transportation, and cargo handling, in a limited and confined area (see Figure 4). The economic planning of the National Government of Vietnam has stimulated growth, which has improved the living conditions of many villagers.

Generally, there are three types of communities living around the Hue lagoon - farming, fishing and aquaculture. Conflicts in demands for the use of space and natural resources arise between different users. In Thua Thien Hue Province agriculture is the main activity and especially in the rice growing areas intensive farming causes increased loading of fertilisers and pesticides into the lagoons. Over the last decade, fishing capabilities have increased rapidly in terms of number of fisher people and boats as well as boat capacity. Fish catch however, has not increased as Figure 3a illustrates. There is reason to be concerned about the status of the lagoon fishery itself. The productivity of the lagoon fishery (in tonnes) has been more or less constant over the 1990s. The productivity per unit effort, however is declining: more people in more boats are catching fewer and fewer fish. It seems that the fishery has reached the limits of its productivity (Field study - ICEM: Vietnam – TTHue, 2003).

Aquaculture has become a priority of the provincial government, especially shrimp farming. The area of shrimp ponds and shrimp production has grown with an exceptional large speed (Figure 3b, see CCC II-8-2). The economic revenues of aquaculture and particularly of shrimp farming are high. However, the creation of fish and shrimp ponds reduces spawning and nursery habitats for lagoon and migratory marine species, affects water quality and disturbs the natural water circulation of the lagoon in dry and wet seasons (see also CCC II-7-1: Thai aquaculture lessons).

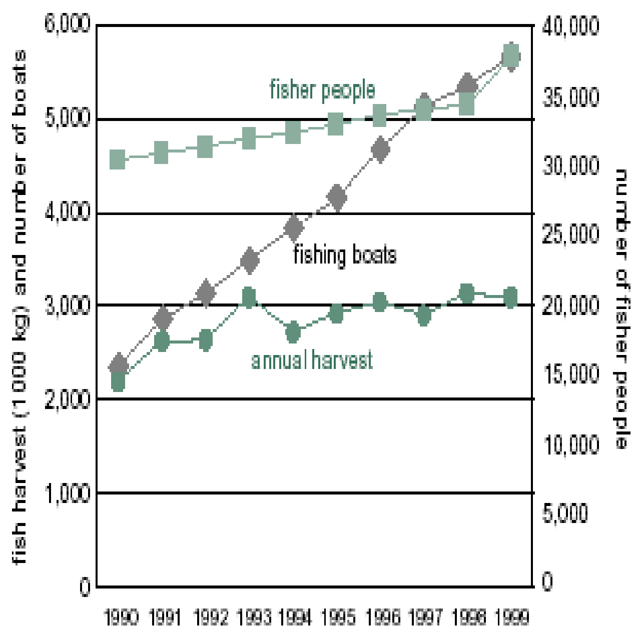


Figure 3a: ***Trends in capture fishery in TTHue:*** *strong growth in number of fisher people and boats, not resulting in growth of annual fish catch; since 1993: a declining productivity per unit effort. (source: Field study- ICEM. Vietnam –TTHue, 2003)*

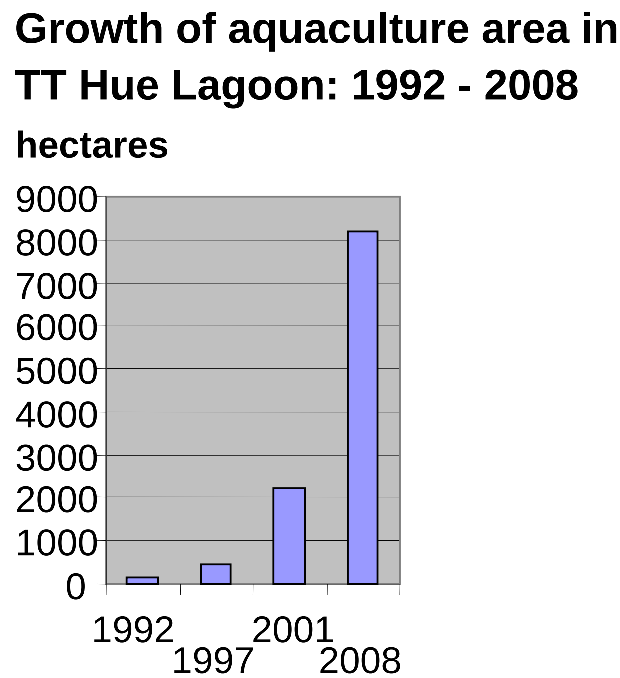


Figure 3b: ***Strong growth in aquaculture in TTHue Province:*** *almost a factor 20 in a decade. Surveyed by sequential Remote Sensing, see CCC II-8-2.*

Consultation of citizens of Thuan An village

Whereas the VNICZM project primarily focused on the "higher-level" strategic ICZM planning activities, the complementary Vietnam-Netherlands Coastal Cooperative Programme (CCP) focused its efforts on monitoring and in depth analysis in specific 'critical' fields for ICZM of special relevance to Thua Thien Hue Province.

CCP activities assisted the Provincial Peoples Committee (PPC) in its planning efforts in the coastal zone, which is so intensively used (see Figure 4). For this, a series of so-called 'Platform' discussions were organised in the fishing village of Thuan An. Interactive discussions in working groups of villagers were facilitated. These helped identify and prioritise the most important problems and issues in the particular commune. Many detailed problems were identified during the discussions and these were combined into the following list of major issues:

- Sewage and waste disposal problems related to health problems and quality of aquaculture products;
- Salinity and water quality problems related to drinking water quality and productivity of rice fields and aquaculture ponds;
- Coastal erosion problems related to safety of villages and cemeteries;
- Flooding problems related to safety and continuity of aquaculture;
- Planning problems related to land use, accessibility for transport and availability and quality of public services.

Figure 4: ***Intense use of the borders of the Lagoon****: rice paddy fields, demanding fresh water, next to brackish aquaculture ponds in Thua Thien-Hue Lagoon system – with large numbers of > shaped fishing nets - see also CCC II-8-2. (photo: Mindert de Vries)*

Identification of drivers and pressures

In order to provide a quick analysis of the situation, the DPSIR approach was adopted (see above). Due to the dominance of aquaculture related issues, elaboration of DPSIR focused on this (Table 1).

Table 1: DPSIR - Driving forces, Pressure, State, Impact and Response - elaboration for aquaculture activities

DPSIR	Elaboration	Information need
Drivers of aquaculture development	Poverty alleviation, Population growth, National economic development planning, Economic development planning in TT-Hue province, Aquaculture planning.	*Insight in planning process and planning programmes. Relevant departments:* *PPC, Dept.of Planning, Dept. of Fishery*
Pressures on the ecosystem caused by aquaculture	Occupation of supra-tidal and intertidal habitats by ponds, Organic waste production, Pesticide use, Impact on water circulation causing worsening water quality, Land use conflicts.	*Analysis of inputs of substances and production of waste loads.*
State of the ecosystem based on indicators	Indicators of the ecosystem state could be: The (remaining/destroyed) area of bare mudflats, wetlands, submerged vegetation, Pollution levels indicated by for instance BOD5, COD, Oxygen saturation, NO3-N, TN, TP, Chlorophyll, algae species composition, pesticide concentrations, Bird, fish and crustacean species abundance and diversity Definition of standards for selected indicators.	*Mapping and monitoring of historical and present states.* *Preparation of indicator values per season, per year, per region*
Impacts on ecosystem carrying capacity	Evaluation of impacts on ecosystem carrying capacity, Analysis of spatial and temporal changes of indicators in relation standards and to (extension of) aquaculture activities in the lagoons.	*Analysis of maps and monitoring data.* *Analysis of existing standards* *Availability of calibrated modelling tools to predict impacts of future scenarios* *Models will also enable integration of other drivers and pressures.*
Responses needed of stakeholders and decision makers	Diversification, decreasing production intensity avoiding diseases, relocation of aquaculture, Improvement of applied technologies, viz waste water treatment, . Improvement of water circulation, Creation & restoration of habitats, Set-up improved monitoring, planning and enforcement programs.	*Clear management information products.* *Inter-agency, inter-sectoral cooperation through ICZM.* *Awareness raising at district and commune level.* *Decisive governance and enforcing*

4.2 Definition of indicators and standards for ecosystem state

The next step in quantifying the state of the eco-system is the definition of a comprehensive set of indicators that relate to the pressures mentioned in the previous paragraph. These indicators require an agreed set of reference values or standards. Once indicators and standards have been defined, the *present* state of the ecosystem can be assessed. Predictions of future values of indicators in relation to aquaculture activities provide a basis for the assessment of the likely impact of development plans, if necessary, in combination with other expected changes or impacts. Mathematical models can improve the predictive capability. The assessment of state of the ecosystem functions (such as providing good water quality), which is based on the analysis of the status of indicators helps define the carrying capacity.

The number of indicators selected is limited by the availability of data, maps that define the historic and present situation and the capability of numerical models that can be used to predict the future state of the ecosystem based on impacts of future aquaculture activities. Furthermore, acceptable standards need to be selected to facilitate evaluation of the measured or predicted indicator values.

A list of quantifiable indicators and standards is given in Table 2. The selection of water quality as an indicator provides a useful start. These indicators can be (and are) measured and used for predictive modelling. Water quality indicators are easily related to accepted standards. Additional relevant indicators of the state of the ecosystem, such as species lists and numbers of birds and fish, surviving habitat (area of bare mudflat, area of submerged vegetation, area of mangrove and salt marsh vegetation) are not used in the remainder of this analysis, due to lack of data and standards, and difficulty of inclusion in mathematical modelling.

Table 2: Indicators and standards of water quality used to measure the state of the ecosystem

Indicator	**Unit**	**Standard**	**Regulations and Provisions**
Total nitrogen	mg/l	0.3 - 0.6	Coastal water standard - Japan
		0.9	Water quality criteria for coastal plain-US
		0.5 – 1.0	Water quality criteria for fish production area - China
Total phosphorus	mg/l	0.03 - 0.05	Coastal water standard - Japan
		0.04	Water quality criteria for coastal plain-US
		0.05	Water quality criteria for fish production area - China
Formalin	mg/l	0.9	Drinking water standard - WHO
		0.001 - 1	Toxicity data to aquatic life (Sara Gräslund, 2001) Formalin is used to sanitize aquaculture ponds
Total organic pesticides	µg/l	10	Coastal water standard for aquatic cultivation area - Vietnam
Total coliforms	MPN/100ml	1000 10000	Drinking water standard -Vietnam– Fishing water - Vietnam

MPN = most probable number

The standard values of selected water quality parameters are preferably based on the Vietnam Coastal Water Quality Standard (TCVN5943-1995) for aquatic cultivation area. Unfortunately, in Vietnam there are no limitation values for Total Nitrogen (TN), Total Phosphorus (TP), specific pesticides and formalin, and standards for Japan, China, US and WHO are referred for those parameters instead. In this study the US standard for coastal plains was used as reference.

4.3 Quantification of ecosystem state using an integrated modelling approach

Analysis of monitoring data

The ecosystem of the lagoon is under heavy pressure. Biological, chemical and physical monitoring of the coastal ecosystem including the Tam-Giang lagoon was pursued by the Vietnam – Netherlands Coastal Cooperative Program (see Figure 5). Water quality indicators such as nutrient concentrations, organic pollution indicators such Biological Oxygen Demand (BOD5), Chemical Oxygen Demand (COD) and Coliforms, chlorophyll concentrations, heavy metal concentrations all point in that direction.

Figure 5: ***CCP monitoring of the Tam Giang lagoon:*** *biological and chemical survey of the water and sediments. (photo: Robbert Misdorp).*

The water quality of the rivers and the lagoon deteriorated measurably during the monitoring period of 1998-2003. BOD5, COD, Nitrate and Chlorophyll concentrations all rose. This indicates that the use of resources in the lagoons exceeds its capacity for natural purification. Due to the lack of data before 1998, it is not possible to quantify long-term historical changes to the biology of the entire TTHue Lagoon (Tam Giang –Cau Hai Lagoon). A number of 'historical' trends seem to be clear:

1) Productive fish catch is centred on migration periods of marine species into the lagoon. In other periods, the catch is very low. This indicates that practically no natural fish populations remain in the lagoon outside of these periods. Fish catch monitoring shows a steadily decreasing size of individuals since the 1990s (Brzeski and Newkirk, 2002) with, a total absence of any adult individuals in the catch data and reduced species diversity today. This is a clear indication of heavy pressure on the lagoons. Fish capture data in relation to number of fishing boats indicates the same (Figure 3a). The strong increasing pressure on the borders of the lagoon is also indicated by the fast extension of aquaculture ponds as shown by Remote Sensing analyses (see Figures 3b and 4; Misdorp et al., 2005 and see also CCC II-8-2);

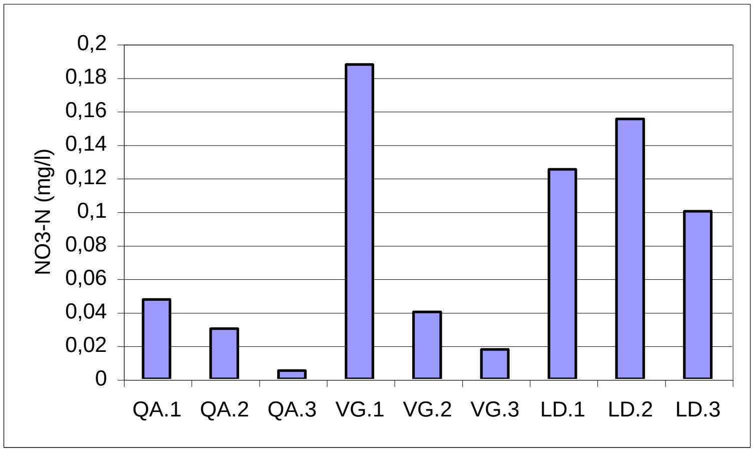
2) Bird species count is down; numbers observed are reduced (Misdorp et al., 2003). Practically no birds feed in the lagoon, indicating that there is no food source of any importance remaining and probably indicating that the amount of undisturbed habitats have been reduced;

3) Macrophyte coverage has been heavily reduced due to extension of aquaculture ponds and enclosures into the shallow areas, destructive fishing methods and the increased harvesting of vegetation for fish feeding;

4) Shallow, muddy and sandy areas have practically disappeared due to occupation by ponds and enclosures, reducing feeding habitat for waders and for many invertebrates;

5) Salinity barriers and sluices built to prevent salinity intrusion in the rivers and to preserve fresh water have reduced the suitability of the area for migrating species.

The results of the monitoring program, initiated by CCP project, clearly illustrates the influence of nitrate enrichment in ponds for phytoplankton production (source CCP Task 7 report, 2003). These gradients indicate the role of the ponds as a source of excess nutrients for the lagoons (Figure 6).



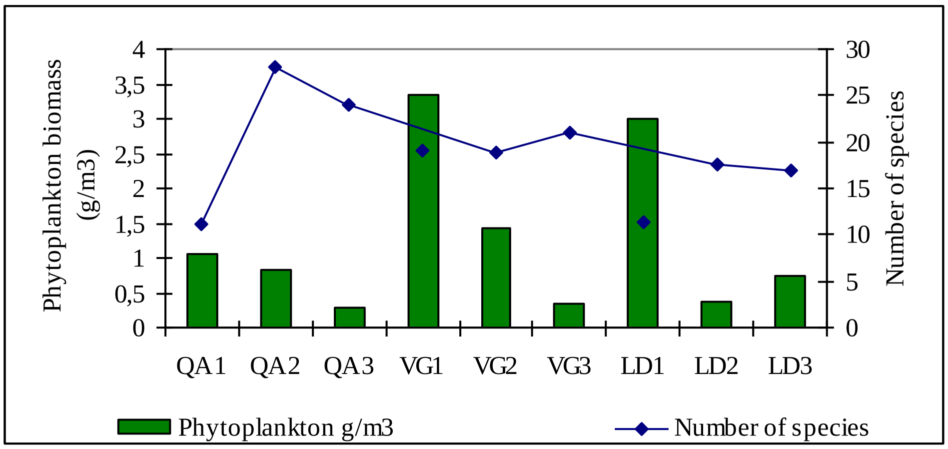


Figure 6: ***Average nitrate (NO_3 – N)*** *concentrations in dry season transects and* ***average phytoplankton biomass and species number*** *in dry season from inside shrimp ponds (# 1), nearby channel (# 2) to lagoon proper (# 3) for three locations: QA: monitoring location in the Tam Giang lagoon, VG: location in the Thanh Lam lagoon, LD: location in the Cau Hai lagoon. (Source: Water quality monitoring of CCP in Thua Thien Hue province in 2002, 2003)*

NO3-N is the dissolved fraction of Total-Nitrogen (TN). This fraction is, during dry season, at high levels of primary production much smaller than the total amount of Nitrogen in the water. The Delft3D lagoon water quality model calculates TN as a combination of dissolved-N, particulate-N in dead organic matter and N enclosed in phytoplankton. This value is later used in analysis of system status against TN-standard. (source: CCP 2003)

Application of numerical models

Based on the results of the DPSIR (**D**riving forces, **P**ressures, **S**tates, **I**mpacts, **R**esponses) analysis, consultation with villagers and availability of data and expertise, a water balance model and a 2D lagoon water quality model were selected as first building blocks for a comprehensive modelling approach as shown in the scheme below (Figure 7).

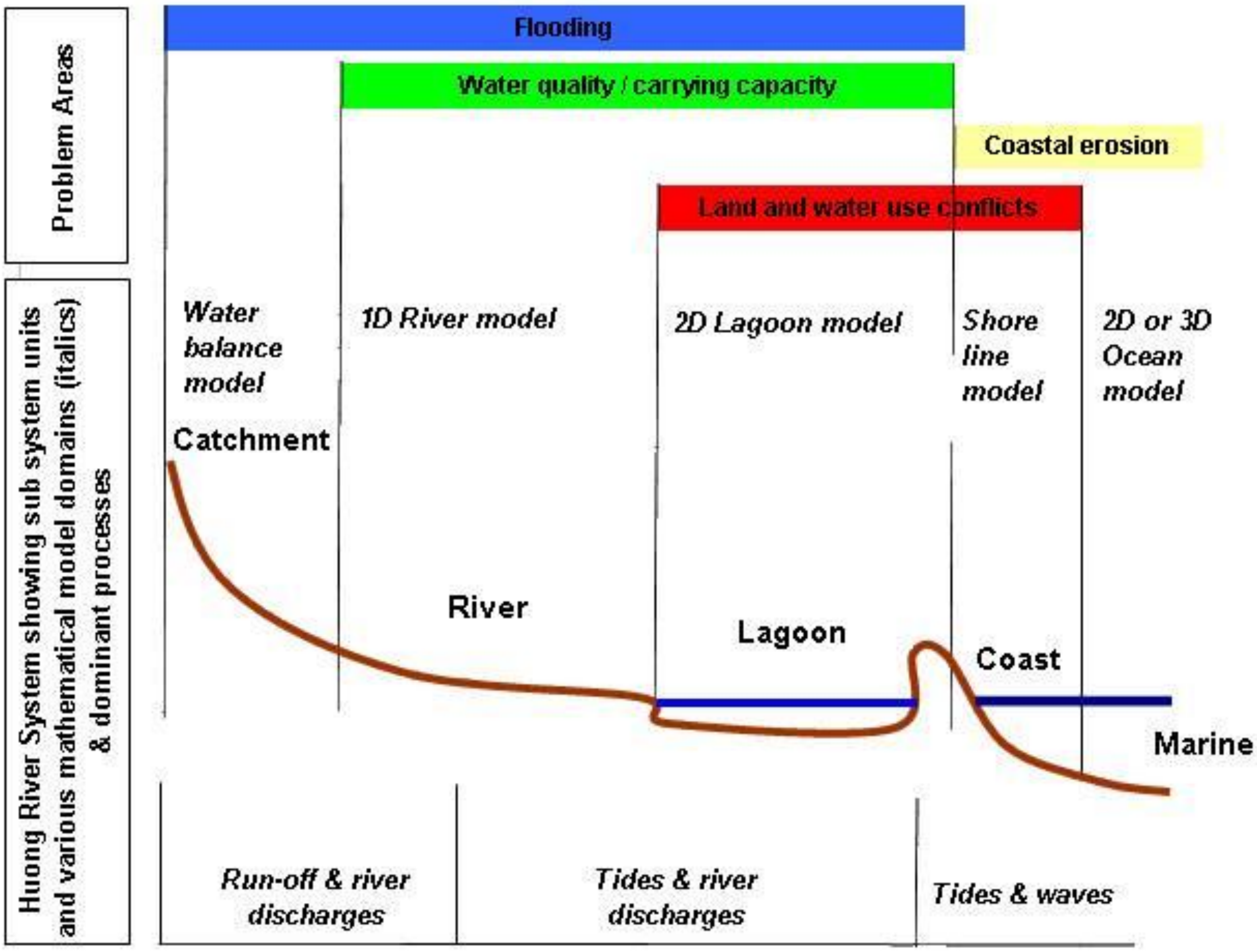


Figure 7: ***TTHue Province : problem issues in relation to water systems and indication of relevant model domains***

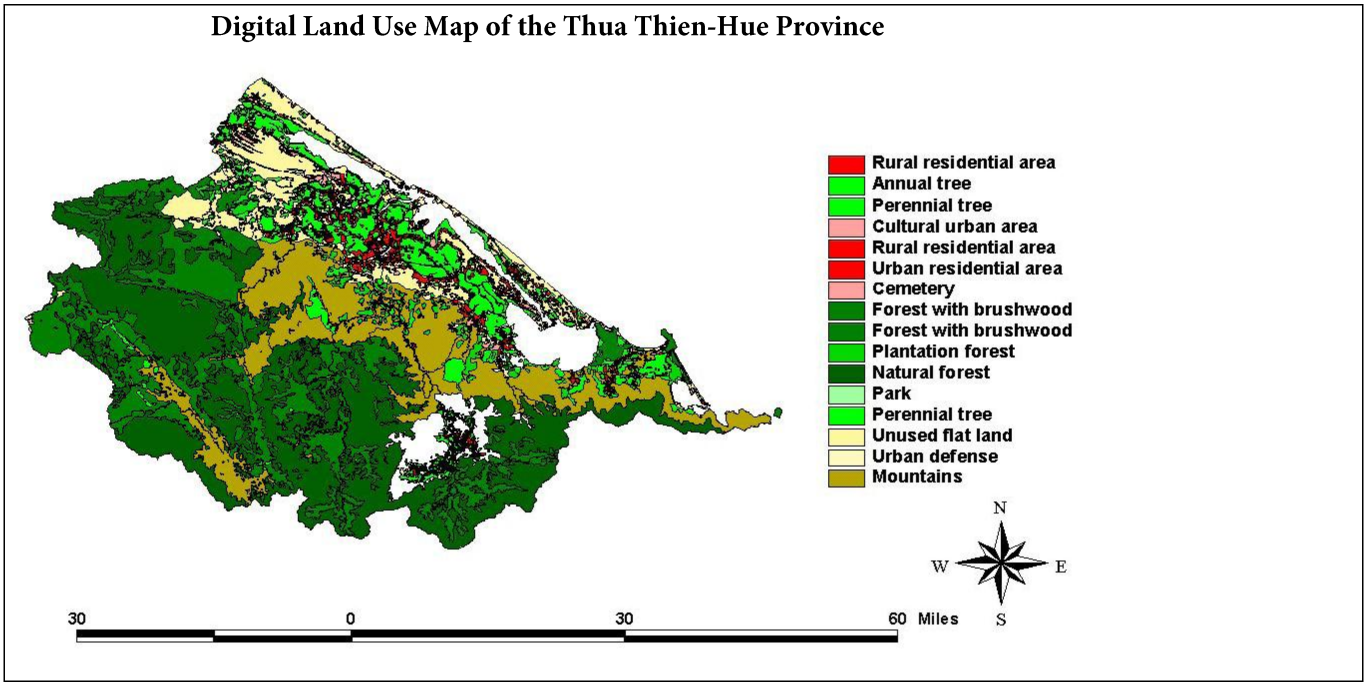
4.4 Run off and River discharges: Water balance model STREAM

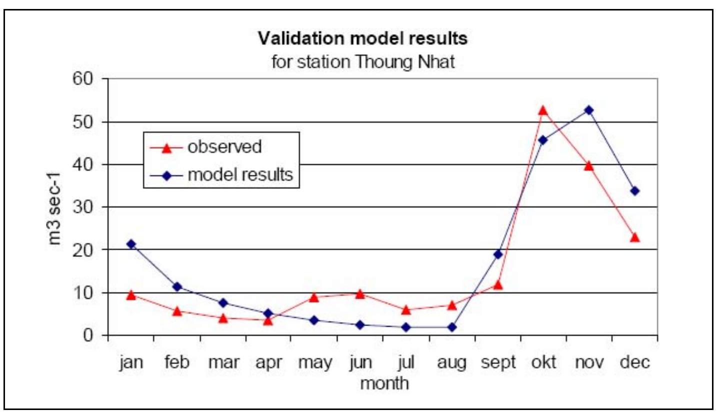
STREAM (Spatial Tools for River basin Environmental Analysis and Management), a GIS based water balance model, was developed in response to specific demands for conceptual integrated river basin and coastal management. It shows the effects of dams and changes in land use in the upper catchment on the coastal zone.

The grid-based STREAM modelling concept was also designed to show the long-term impact of climate change on the entire river basin. Within the context of the CCP project, the Institute of Environmental Studies (Free University, Amsterdam, see CCC III-3-2-6) developed a STREAM model for the river basins of the entire TTHue Province, including the main Perfume River (Huong). It was calibrated and validated in order to predict river discharges into the lagoon (Aerts and Bouwer, 2002). Figure 8b shows the validation results of the STREAM model for the Thoung Nhat station (data in the Vietnam VA report, 1995), upstream on the river Huong (Perfume). The observed and modelled river discharges were a relatively close fit. The STREAM drainage pattern fitted well with the actual river courses (Figure 8c).

This model is able to predict river discharges using land-use (see Figure 8a), soil types and rainfall-runoff relations based on the current knowledge and statistics of the Huong river. Impact of climate change affecting river discharges were also estimated, using IPCC regional scenarios on monthly temperature and rainfall as input data.

STREAM-TTHue provided river discharges, as crucial input to the 2D Lagoon model, thereby linking processes in the hinterland to the coastal area.





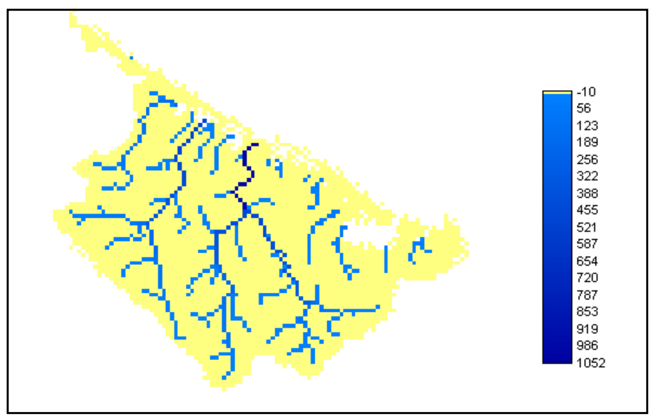


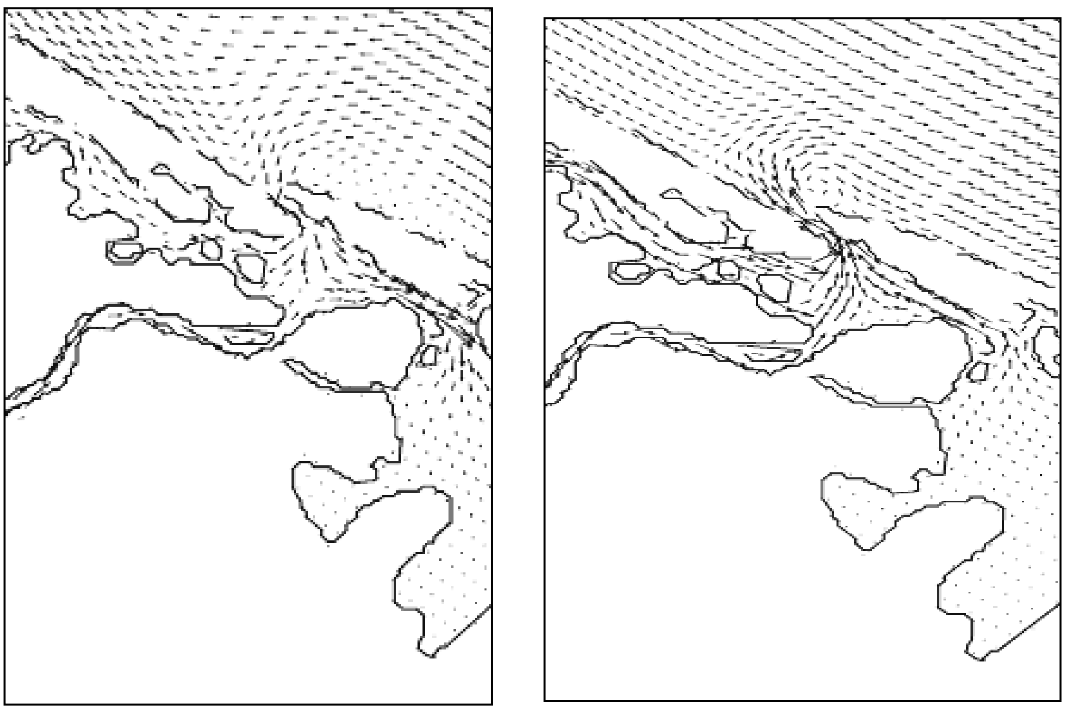
*Figure 8a**: Digital land use map of TT Hue Province**, one of the series of GIS input data for the water balance STREAM. (source: IMER, Haiphong);*
*Figure 8b: **Validation of modelled monthly river discharges** with STREAM, using the hydrological data collected at the Thoung Nhat station, upstream Huong river;*
*Figure 8c: **The simulated STREAM drainage patterns and river discharges (m3/sec)** for November 1999, included the heavy rainfall related to cyclone "Eve", (first week of November 1999) reflects rather well the actual discharges and the drainage patterns of the river basins in TTHue Province.*

4.5 Water circulation and water quality, 2D Lagoon Model

With this model, many important features and behaviour of the lagoon system were quantified, including:

- Salinity distribution;
- Sediment transport;
- First order degradable substances.

The 2D Lagoon Model is used for modelling variable water flow and transport of dissolved matter. The flow is determined by the lagoon bathymetry, tides (tidal inlet bathymetry), river discharges, currents and wind (waves). The model solves the shallow water equations, consisting of the horizontal equations of motion, the continuity equations and the transport equations for conservative constituents (e.g. pollutants). The equations are solved by an implicit finite difference method on a staggered grid. The transport of matter is modelled by advection-dispersion equation in three co-ordinate directions. Source and sink terms are included to simulate discharges and withdrawals. A first order decay rate can be defined for each constituent. Improvements of the model are necessary with respect to the bathymetry (for the lagoon an assumed uniform water depth was 2m), extension of the grid to include land liable to tidal flooding and calibration /validation with better (tidal) data. Because in general locally generated waves are small (below 30 cm) no wave modelling is necessary. The basis for the Lagoon Model is the existing DELFT3D-FLOW modelling environment (see also: http://delftsoftware.wldelft.nl/)



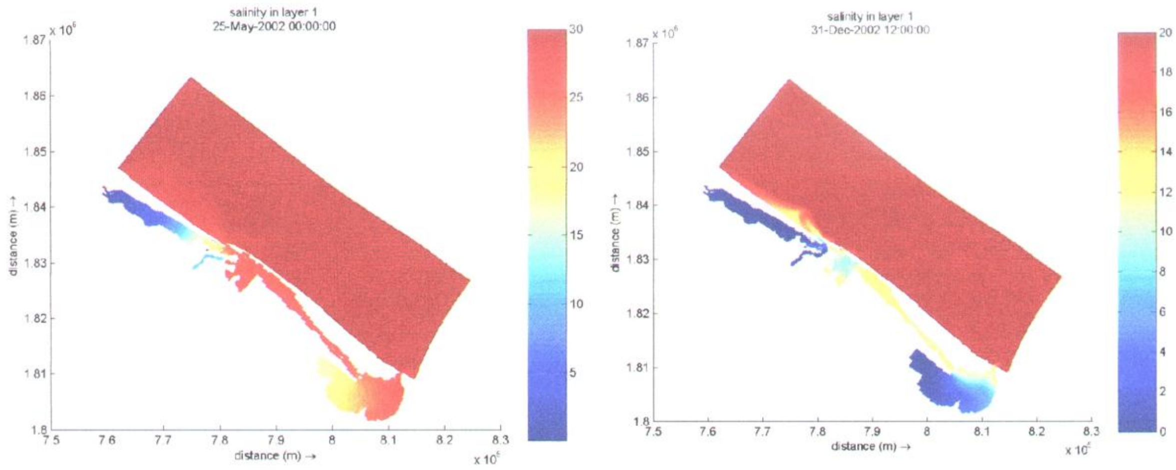


Figure 9a: ***An example of the flows at flood and ebb tide in the Thuan An area*** *(above) and*
Figure 9b and c: ***Distribution of simulated salinity*** *(in promilles salt) produced by the 2D hydrodynamic model developed through the VNICZM project: salinity ranges up to 30‰ during dry season (left) and up to 15‰ during wet season (right).*

The state of the ecosystem has been evaluated. This was done on the basis of application of the 2D Lagoon Model, the discharge data derived from the Water Balance Model STREAM, the impacts of aquaculture comparing the situation 1990, 2001 and two future (2010 a and b) scenarios regarding land-use (Table 3). The numerical model was used to establish concentrations of the nutrients and pesticides in four major parts of the Tam Giang – Cau Hai lagoon. The 2001 situation was used to calibrate the model results to the available monitoring data (N.T.T. Nguyen, 2004).

Table 3: Situations studied with the 2D Lagoon Model

Situation	area of aquaculture (ha)	Remarks
Historic 1990	0	
Calibration 2001	2976	calibrated to data
Future 2010a	7104	following master plan, high estimate
Future 2010b	7104 + reservoir	60% decrease discharge wet season 40% increase discharge dry season

The calculation results shown that at present the lagoon is polluted somewhat by nutrients during dry season with average concentrations close to the standard. The most polluted areas have been found at river outfalls and aquaculture ponds. Agricultural waste is the main pollution source in 2001 (Figure 10).

Based on the provincial master plan, aquaculture area was expected to triple between 2001 and 2010. This trend is indeed realised (Figure 3b). Subsequently, the total future nutrient load will also be doubled or tripled depending on choice of culturing techniques. In the same way, loads of pesticides from the aquaculture ponds to the lagoon, will increase. This estimate of future waste loads is based on increasing area without increased unit load. This is probably a conservative estimate. In the same period nutrient load from population will increase due to population growth and loading from agriculture will increase likewise.

The future increase in concentrations of the pollutants can be predicted based on the above trends in waste loads and using models which quantify and extrapolate the hydrodynamics and chemical processes in the coastal zone. For the future situation, nutrient level rises alarmingly in the entire lagoon during dry season. With the expansion in aquaculture area by 80% and the increase in waste load per ha by 50% together with the slight increase in agricultural load (the future scenario with low aquaculture load), the future nutrient content is about 1,3 times for Total Nitrogen and 2 times for Total Phosphorus as much as the 2001 concentrations.

Figure 10 shows that the contribution of aquaculture to the total nutrient load in the lagoon will increase from the present 15-20% to 60-70% in the future. The selected standards for Total Nitrogen and Formalin are already exceeded in the present situation. Total Nitrogen -TN standard is exceeded in 35% of the lagoon area in the dry season and this level will be surpassed in the future (2010). The difference between dry and wet seasons is striking, due to the drastic changes in river discharge, water residence times and water circulation in the lagoon.

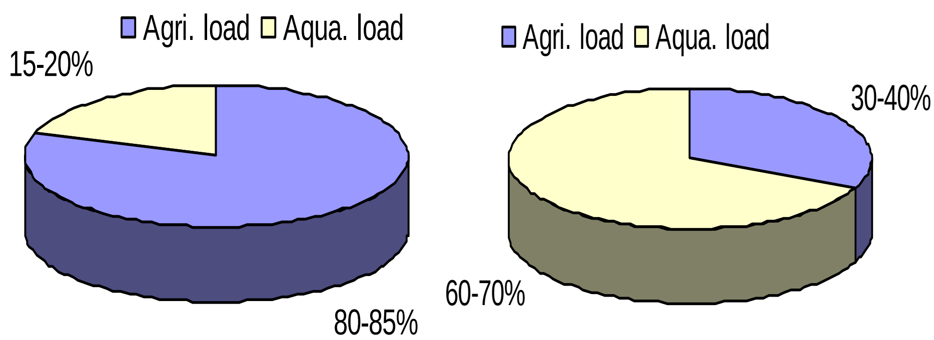


Figure 10: ***Relative contribution of aquaculture to total nutrient load 2001 situation (left), 2010 situation (right)***

With respect to area exceeding standards, the model simulation indicates that in 2010 about 50% of total area could exceed the Total Nitrogen (TN) standard value for the United States of America. As this US - TN standard is a high value in comparison with other standard values (see Table 2), more areas of the TTHue lagoon will exceed the limit if other standards would be applied. The same pattern is observed for Total Phosphorous (TP). The area polluted by nutrients during the dry season is larger than during wet season. However, there is an opposite trend for the third group of pollutants, the pesticides: the polluted area during the dry season is smaller than during wet season. This is related to seasonality of application of pesticides, which is linked to the cropping cycle of rice and the growing season of aquaculture species (see table 4).

Table 4: Exceedance of standards calculated with 2D Lagoon Model (percentage of total area)

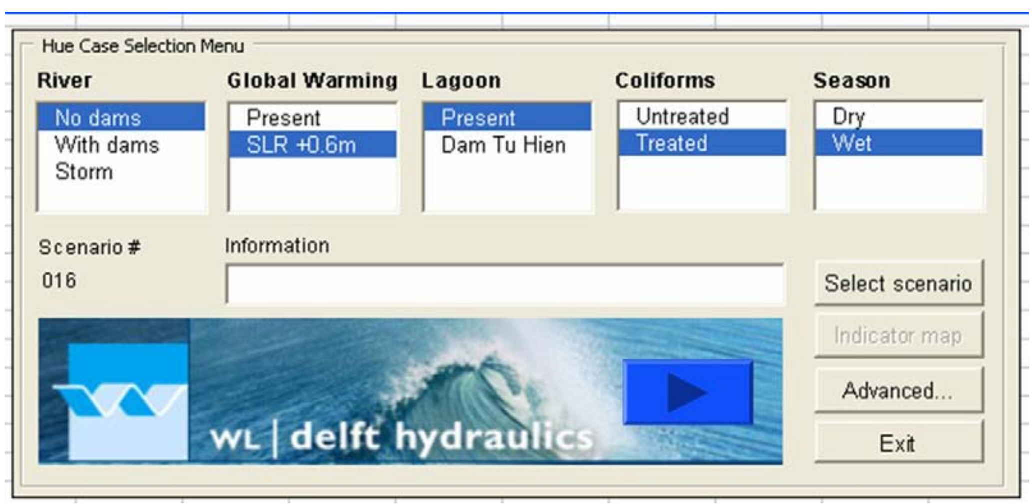
Situation	TN (US std)		TP (US std)		Total Pesticides		Formalin (toxic effects)	
	wet	dry	wet	dry	wet	dry	wet	dry
Historic 1990	0	0	0	0	0	0	-	0
Calibration 2001	0	35	0	50	0	0	-	38
Future 2010 a	30	50	10	85	35	10	-	50
Future 2010 b	70	42	25	78	50	5	-	50

Future estimates are based on the possible influence on river discharge by the envisaged dam construction across the river creating water storage reservoirs. Other activities in the province (changes in land use and soil erosion, new infrastructure,) and climate change (changed precipitation and evaporation) will further affect the state of the ecosystem. These changes can be quantified and related to river discharges, sediment balance, and water circulation in the lagoon itself and can facilitate the estimates on the future exceedance of nutrients and pollutants as a part of the integrated ecosystem approach.

5. Advise to management level

This analysis of the impact of aquaculture on the state of the lagoons is the first attempt to provide a consistent analysis of ecosystem functioning, where both influences from land and sea are integrated and where biological and physical processes are combined. The analysis of historical, current and future states of the lagoons has produced valuable understanding of the sensitivity of the lagoon to increasing use. The application of a standard numerical hydrodynamic and water quality models with a simplified interface provided the decision-maker with a generic tool to analyse the impact of pressures on the lagoons. It is clear that this approach provides managers with greater insight into the possible consequences of economic planning decisions on the functioning of the lagoon.

From the results of this study, it appears that the maximum carrying capacity of the lagoon for waste loads from aquaculture has been reached. The dry season is the most sensitive to pollution from aquaculture. A remaining important issue, which requires discussion, is the allowable area where standards can be exceeded. If only 5% of the lagoon area is allowed to exceed the standard in the dry season, then it is obvious from Table 4 that the present (2001 situation) surface area in which aquaculture takes place is too high. The level by which the standards are exceeded is not very different between the four sub-lagoons that have been studied. We should also acknowledge that the reference situation chosen was 2001. Since then the actual area of aquaculture has grown rapidly to over 8000 ha in 2008 (the year this study was executed). We need to acknowledge that the loss of shallow natural habitat (needed for spawning of many fish species) is almost 100% due to pond construction and therefore exceeds any sensible definable standard. Impact of reservoir operation in dry seasons will improve the situation slightly, due to extra water supply and dilution. In the wet season, the situation will deteriorate further due to water storage and reduced dilution.



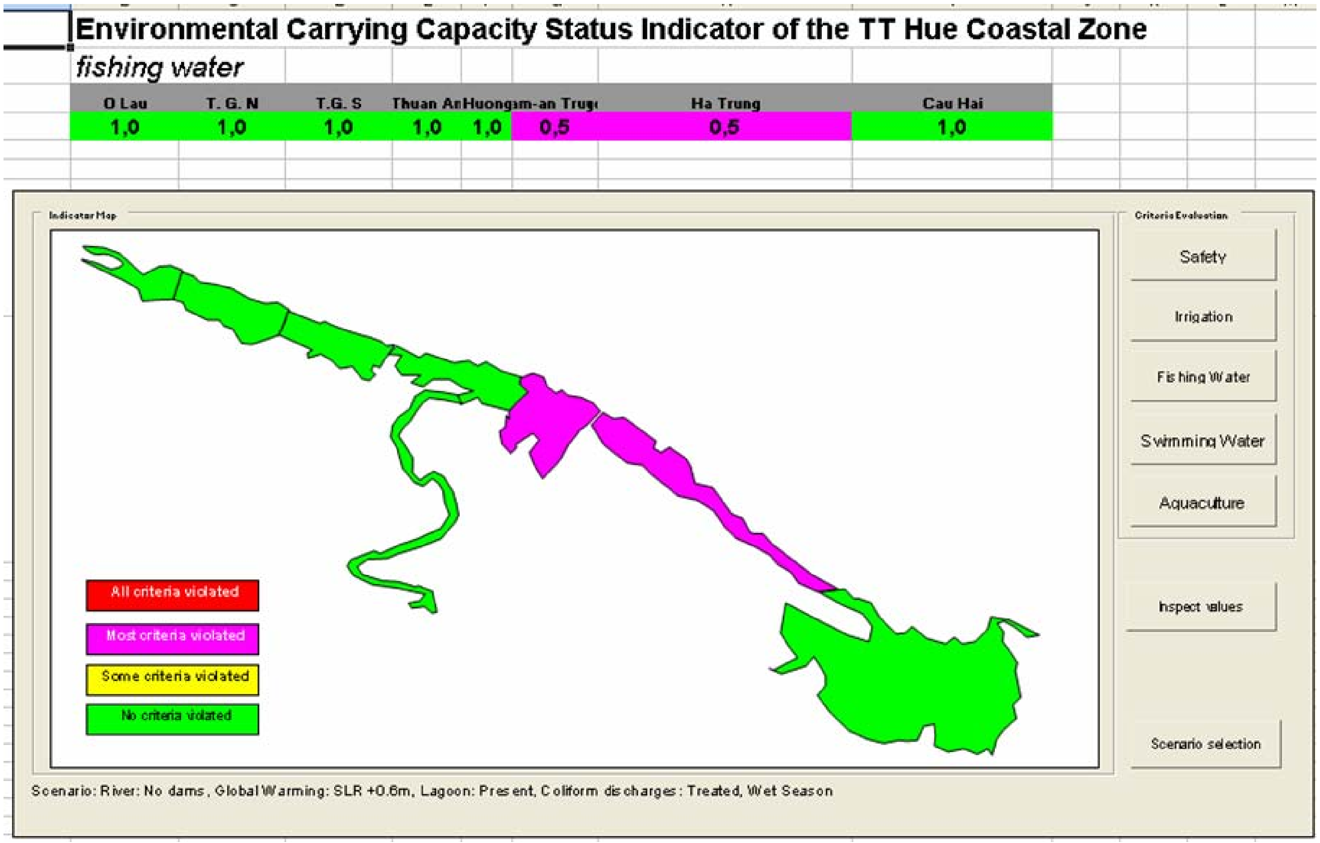


Figure 11: ***Simplified model interface allowing analysis of several cases on ecosystem state****. This interface overarching the combined results of Water Balance Model STREAM and 2D Lagoon model, provided an ecosystem state evaluation on highest level of integration possible within the CCP project. Analyses provided information in relation to river discharge, precipitation, evaporation, land use, aquaculture intensity and season. Indicators and standards are selected according to issues at hand. For instance, the state of the lagoon as fishing water is based on testing calculated average concentrations in each sector for exceedance of TN and TP and Total Coliform standards, as given in Table 2.*

TT Hue provincial leadership is trying to find ways to quantify the impact of aquaculture activities on the environment, and properly guide the rapid growth of aquaculture activities in the province in the future. This is required in order to ensure sustainable further development of this important economic sector, whilst ensuring the maintenance of a healthy ecosystem for the benefit of other sectors and society in the long term. In view of the present situation, the following advice was given to the Provincial leadership with respect to sustainable further development of aquaculture activities:

- Stop further extension of aquaculture areas in order to prevent further habitat loss. Given the present situation, relocation does not seem an effective option;
- Fix the waste load of aquaculture production at the level of the present (2001) situation
- Start pilot studies on small- or no-emission culturing technologies that can lead to increasing productivity, while reducing environmental impact at the same time, which is in line with the findings of Gräslund and Brengtsson (2001). New technologies should replace old culturing systems, without further expanding the area. Nett reduction of total waste load should be the ultimate goal;
- Research the possibilities for reducing the discharge of nutrients and pesticides from the drainage basin into the lagoons (priority area: Cau Hai);

- Research the possibilities for reducing the nutrient input from domestic sources (for instance, introduction of phosphate free detergents);
- Implement measures to reduce bacteria, BOD and heavy metal load to the lagoon system by treatment of sewage and industrial waste and introduce home sanitation units, see CCC III-3-3-6;
- Research options for improving water circulation in order to improve water quality in the most critical culturing areas. If locally applied, this option can lead to better water quality in ponds, but will cause a deterioration of the water quality in the lagoon proper. If applied regionally, in order to improve mixing of seawater with lagoon waters, it could lead to investment in large-scale infrastructure works. This option could be promising but needs detailed numerical modelling studies;
- Study options for creation/restoration of lost habitats. This option could imply reduction of the extent of aquaculture in some areas and designation of protected nature areas. It could also result in creation of new habitats in other areas. For instance, a protected island in Cau Hai lagoon surrounded by shallow intertidal areas could be created. Another option is to create mixed aquaculture ponds, with shallow areas that can provide habitat for submerged vegetation or mangroves, at the same time filtering suspended solids, improving water quality, feeding, and sheltering the cultured species;
- Set-up of an improved long-term monitoring programme. This is necessary in order to monitor the future changes of the ecosystem state in relation to the present day situation and will help to assess the effectiveness of management measures;
- Set-up a long-term interdepartmental ICZM training programme in cooperation with universities. This program should form the basis for trained experts and provide a source of adequately educated master students and PhD's that can sustain ICZM in the future, use all experiences and materials available, such as the Thai Aquaculture Training Manual, see CCC V-1-1;
- Improve the quality of data and modelling, in order to provide greater certainty in model predictions and therefore in management advice;
- Create an international and inter-university cooperation in the field of integrated ecosystem monitoring, modelling and policy preparation. This integrated ecosystem approach will help the application of good governance for the sustainable use of resources in the coastal zone of the TTHue Province and can function as a framework to implement many of the recommendations.
- Learn from the experiences of Thai Aquaculture Boom and Bust waves, which provided a few investors with high economic benefits, left many local coastal inhabitants with distress, caused large scale ecosystem disruption and left the Government with expensive rehabilitation projects, see CCC II-7-1.

6. Conclusions

One of the main purposes of the Vietnam- Netherlands Coastal Cooperative Programme was to develop tools, examples and capacity, which will help strengthen the integrated approach with respect to sustainable decision-making for the management of the TTHue lagoon and its surroundings extending: from the catchments to the coastal areas. Training was a fundamental part of the project. It was clear in the beginning that the ICZM capability in Hue was limited. Capacity building and institution setting at the local level to create ownership took a considerable time. From this perspective, involvement of experts from national institutes proved to be valuable to improve quality advice to experts and policymakers at local level. In the spirit of the ICZM concept, the Provincial Leadership received preliminary but integrated and timely answers to their questions on future policy decisions.

Does this help to provide good governance?
The analysis shows that urgent action is needed with respect to the following:

- Physical state: *tools are needed to improve understanding and investigate solutions;*

- Water quality and pollution: *Any intensification and/or extension of activities in the future should be carefully controlled and limited;*
- Ecology: *Fishing intensity should be reduced and natural shallow habitats should be protected and partly restored;*
- Governance*: More capacity of ICZM experts is needed to facilitate the ICZM process. High level governance structures are needed to facilitate implementation of integrated measures and to prevent execution of unbalanced and unsustainable mono-sectoral developments.*

The ecosystem approach can help government to apply good governance for the sustainable use of resources in the coastal zone. Good governance here means sound resource use policies that are responsive to the economic needs of the people and in the mean time maintain a healthy eco-system. Robust and sound resource management systems, practical experience and knowledgeable institutions are required to support these policies. Good governance at all levels is fundamental to finding a balance between economy and sustainable development. To this end, it is important to ensure inter-sectoral cooperation, optimal institutional setting and reliable funding in the pursuit of good governance of the coastal system. There is an urgent need to integrate the ecosystem approach into agriculture, fisheries, forestry and other production systems that have an effect on effective, long term use of resources and biodiversity.

Long-term capacity building will help strengthen provincial ICZM capability by improving the level of education in local Universities particularly in those fields related to natural (water) resource management (biology, environmental studies, chemistry, geosciences and coastal zone management). This recommendation should include a long-term inter-university cooperation project between National and Provincial levels and between Vietnam and other countries. The creation of such a cooperation in the field of integrated ecosystem monitoring, modelling and policy preparation will strengthen the sustainable use of resources in the coastal zone within a frame of optimal institutional arrangements. A successful example of such an ongoing inter-university cooperation between Vietnam and the Netherlands exists namely: the creation and support of the Marine and Coastal Engineering Faculty of the Water Resource University in Hanoi (see CCC II-8-5).

The long-term development objective of this recommendation is to raise the performance level of professionals working in ecosystem research in Vietnam, and to establish a firm foundation for well-qualified graduates to take up positions in research, operation and management functions in governance and business in the coastal provinces of Vietnam.

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