COASTAL AQUACULTURE AND ENVIRONMENT: STRATEGIES FOR SUSTAINABILITY

Research Project R 6011
Final Report to the
Overseas Development Administration

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EXECUTIVE SUMMARY

1 Project R6011 was designed to identify the constraints to sustainability in coastal aquaculture as modelled by shrimp farming. It has built on knowledge developed from the earlier project, R4561 which examined environmental constraints. Project R6011 has shown how environmental factors together with economic and social factors all have their role in the lack of sustainability of the present systems.

2 This work was carried out by surveying a wide range of shrimp farms in Southern Thailand with respect to characterization of farms, management strategies, construction and production costs relative to income. This knowledge base was extended with additional information obtained from commercial and other sources and also by monitoring water quality and soil data from the farms themselves. This gave a detailed picture of the interaction between environment, and economic and social factors in shrimp culture, the constraints for which can vary in particulars even on a close geographical scale. The breadth of the survey however has allowed a framework to be constructed that is of far wider application than its immediate source.

3 The project also analysed data from Project R 4751 to investigate critical water quality data and establish a relational data base, and to build a model to investigate the dynamics of the nitrogen components in the system. Both the survey work and the model construction have allowed the clarification of where the system sensitivities lie and therefore where management changes can be made most effectively.

4 Based on the outputs of the work, and through the use of a multiple-element sustainability assessment approach developed within the Institute of Aquaculture, the key constraints to sustainability have been identified as :-

- the high risk inherent in the culture system and its environment, related to land tenure and associated social issues,
- economic risks, credit access and implementation,
- viral disease introduction to farms and transfer between farms/regions
- water quality, its management, and knowledge associations,
- market pressures, and the lack of long term policy and management structures supporting investment in sustainable systems
- inappropriate education, training and information delivery for farmers
- lack of participation in decision making at all levels of the industry and within coastal management policy.

5 The project has made significant inputs into ODA development goals by providing a better understanding of the impacts of aquaculture development in the coastal zone - highlighting the strategic options for mitigation that need to be developed and promoted. It has also illustrated how fears of disease within a system can lead to management practices that can promote stress within the system compounding the problem.

6 From this more integrated perspective of sustainability (economic, environmental and social) it may be hoped that better understanding can allow more effective, strategically oriented policies be proposed for supporting productive, environmentally sound and socially beneficial production in coastal environments.

1) BACKGROUND

In many parts of the world, coastal aquaculture is experiencing declining productivity associated with poor environmental management. There are many forms of artisanal coastal aquaculture systems, but their small scale limits their impact. Shrimp farming is however on a sufficient scale to make significant impacts worldwide. The development of coastal areas for shrimp farms has been particularly notable in Asia due to the potentially high financial returns and the ability to generate export earnings. The area under cultivation, intensity of production and the financial scale involved creates impact at local, national and regional level. From a sustainability perspective such impacts are still poorly understood and this had led to an over-generalization of the effects of shrimp farming on coastal areas.

Cultured shrimp currently account for ~ 30% of the 2 x 10^6 t of world production, of which 50% is the black tiger shrimp *Penaeus monodon* cultured in SEAsia. The high price for shrimp coupled with cheap land costs and simple but inefficient production systems led to rapid expansion of shrimp culture, closely followed by collapse. In Taiwan production collapsed over three consecutive years (80,000t in 1988 to 9,000t in 1990). This led to the expansion of the Thai industry which is now experiencing similar collapses. In 1989-90 an estimated 45,000ha of shrimp farms in the northernmost part of the Gulf of Thailand were abandoned due to consistent crop failures; they remain unused today. This has encouraged intensification in other regions and the exploitation of new areas as the opportunity to farm shrimp becomes available. There has been rapid development in many SEAsian countries as intensive culture practices became feasible (India, Vietnam, Bangladesh, Indonesia, Philippines, China).

Thailand's shrimp culture area is variously estimated to be 40,000 to 80,000ha (Menasveta, 1992; Briggs and Funge-Smith, 1994) although a reasonable estimate may be ~ 60,000 ha. More than 80% of Thai *P. monodon* culture comes from 12,500 intensive culture farms with a total area of 27,000 ha (6.5 t $ha^{-1}yr^{-1}$, Kongkeo, 1994). The industry as a whole employs more than 150,000 people of which some 97,000 are directly involved in shrimp farming. It is estimated that 500,000 households are connected in some way with shrimp farming and that for every 1 Baht of shrimp produced there are ~ 3.5 Baht in associated industries (Kongkeo,1994; World Bank, 1995). In 1991 shrimp became the 5th largest export in terms of revenue and by 1993 had increased 9% to 4th position with a value of 37,841 million Baht ($US 1,514 million) (NACA,1994; Bangkok Post, 1994). The impacts of the coastal shrimp culture industry have been observed across a range of environmental, economic and socio-economic factors (Chua, Paw and Guarin,1989; Csavas, 1993; Flaherty and Karnjanakesorn, 1995; Lin, 1989; Macintosh and Phillips, 1992; Mahmood, Chowdhury and Saikat, 1994; Panvisavas, Agamanon, Arthorn-Thurasook and Khatikarn, 1991; Paw and Chua, 1991; Primavera, 1991, 1992, 1994, 1995). However, few studies have been concerned with more than one of these issues at a time. The result has been a fractured knowledge of the constraints to sustainability.

The immediately critical aspect of sustainability concerns declining productivity in older farms. This has been principally due to poor management techniques, coupled with a tendency to overstock and overfeed. High farm densities and poor seawater quality have exacerbated these problems, resulting in the closure of farms and dereliction of huge areas of coastal land. The emergence of highly pathogenic viral diseases ('Yellowhead' and 'White spot') over the past 3 - 4 years has caused major crop losses in many areas, with serious economic and social consequences. Whilst an affected area may recover in time, the financial impact and altered resource use structure can cause irreparable damage to coastal communities. This is especially so where small investors and farmers have borrowed heavily to enter shrimp farming, and/or where traditional forms of livelihood have been abandoned. The effect of viral diseases has also pressured farmers into using alternative management strategies to minimize infection. Unfortunately these strategies have not only been unsuccessful at preventing viral disease, but have presented problems in their own right.

In some countries of SE Asia, small shrimp farmers can represent the majority of stakeholders in coastal aquaculture. These farmers have diversified away from subsistence farming or fishing towards a financially more rewarding livelihood. This change of livelihood can be irreversible as they may use their only assets (land, boats, etc) to generate capital or credit to enter in business. In other cases/countries shrimp farmers can represent a wealthy elite who are able to enclose coastal land for farm development to the detriment of other resource users. Shrimp farming can become a significant source of income in coastal areas employing labour at every level, from pondside to processing. The infrastructural changes that can accompany shrimp farm development can be positive. The change of livelihood and resource use in coastal areas that accompanies shrimp farm development can also reduce urban migration from these previously poor areas. There is a concern however, that decreasing diversity of resource use into a single industry may have serious consequences should that industry subsequently fail. There is an urgent need to develop effective production systems, to control disease transmission, minimise environmental degradation and to rehabilitate derelict areas. This will require a complete re-evaluation of current shrimp culture techniques and their integration into the coastal environment.

Sustainability objectives can be considered in terms of three basic systems : the biological or natural environment system; the economic system and the social system. Since these three systems often have conflicting goals, the objective of sustainable development is to maximise the positive sustainability features of the three systems, and this process inevitably involves choices and compromises (Barbier, 1987). The values assigned to the different components of any system by the different stakeholders will affect their perception of its sustainability. It is also important that, when assessing the sustainability of a coastal aquaculture system, it is viewed as an integral part of the coastal ecosystem rather than a discrete entity. The environment system was the subject of investigation under ODA Project NO 4751 and the understanding built up from this work led to the identification of this more holistic approach.

The relative contribution of economic, biological/environmental and social factors in determining sustainability varies according to different farming situations and value judgements. For the purpose of this project, it is accepted that the Thai shrimp industry is already developed, thus issues of sustainability must focus on maintaining production, increasing resource use efficiency and minimizing further impact on coastal resources. It is important to realize that whilst general sustainability strategies may be broadly applicable, the reality of their implementation usually results in considerable compromise. What coastal aquaculture (and shrimp farming in particular) requires, is an approach that enables shorter term achievable objectives to be identified and implemented within a long term development strategy.

Shrimp farming represents an excellent example of the conflict between aquaculture and coastal resources. It is certainly the most pressing problem in many tropical developing

In many respects, shrimp farming represents an excellent example of the conflict between aquaculture and coastal resources. It is certainly the most pressing problem in many tropical developing countries' coastal aquaculture due to its economic, environmental and socio-economic consequences. The diversity of issues that affect the interaction of aquaculture (shrimp farming in particular) and the coastal environment has presented difficulties in identifying the constraints to their sustainable development. There is a need for a holistic (environmental, social and economic) approach to the identification of these constraints and formulation of appropriate strategies for their implementation.

2) PROJECT PURPOSE

The project's purpose lies within the broad framework of improving scientific and technical knowledge of coastal aquaculture systems and of formulating more effective strategic and specific management approaches for coastal resources and their dependent communities. To more fully understand the management strategies employed in these coastal systems and to identify sustainability criteria, a range of technical, environmental and socio-economic elements must be considered. Based on currently operational shrimp production systems and their surrounding socioeconomic and environmental context, the project has aimed to link existing environmental and technical knowledge with field data and experimental trials to develop a broader perspective based on technical, environmental and socio-economic factors. The effect of farm size, intensity and culture system was investigated, as were novel low impact production methods, including the use of pond liners, water recirculation, effective micro-organisms, closed systems, storage reservoirs and integrated systems. In a multidisciplinary approach, the project derived inputs from the Institute of Aquaculture (IOA), University of Stirling and the Marine Resources Assessment Group (MRAG) Ltd., University of London. The component objectives can be grouped as follows:

- i) *Development of sustainability context for coastal aquaculture* (IOA); comprising data collection from different farm systems in different areas. Quantification of production intensity, fixed costs, environmental parameters, management techniques and farm character. The collection of socio-economic information regarding employment, labour costs, job diversity within the areas studied will be attempted.

- ii) *Integrated and other systems for low-impact production* (IOA); based on experimental trials to validate the integration of shrimp culture with bivalve/fish seaweed culture, and the potential of alternative approaches, such as the use of bacterial water quality improvement compounds and lined pond systems,to improve biological sustainability.

- iii) *Water quality management* (MRAG); investigation of critical water quality management parameters and their effect on farm impact and sustainability, based partly on data collected during ODA project RD 4751, and also on new inputs from the present project.

- iv) *Integrated production strategies* (IOA/MRAG); based on integration of water quality/management models with data concerning farming systems. The intention is to develop a method for assessing the components of different shrimp culture systems in environmental, economic and socio-economic terms.

3) RESEARCH ACTIVITIES

These were carried out as planned in the project framework although following the results from the initial experimental trials in component (ii - Integrated and other systems for low-impact production) it was decided to extend the work to include an examination of the potential for alternative culture systems. These included bacterial water quality improvement compounds and lined pond systems. The work was carried out in the Institute of Aquaculture, at MRAG, and in Thailand. The survey work would not have been possible without the Thai language/southern Thai dialect knowledge of Dr Funge-Smith and without the help, hospitality and resources of the Tinsulanonda Songkhla Fisheries College (TSFC). Assistance with methodology in the collection of socio-economic data was obtained from Bath University School of Social Sciences and the Faculty of Environmental Management, Prince of Songkhla University, Hatyai. Finally, important strategic inputs on sustainability assessment methodologies and on framework development were provided by Dr J Alan Stewart of the Institute of Aquaculture, University of Stirling. Key personnel included:-

Institute of Aquaculture
Dr Janet H. Brown, University funded Research Lecturer, Project Coordinator
Dr Simon Funge-Smith, ODA funded Research Fellow

Marine Resources Assessment Group Ltd
Mr Kai Lorenzen (Coordinator and Modelling Specialist)
Ms Vicki Cowan (Research Assistant)
Mr Mark Aeron-Thomas (Consultant Economist)
Ms Juliane Struve (MSc Candidate)
Mr Caradoc Jones (Database Specialist)

Support staff, Thailand
Mr. Vinai
Mr. Dong

Research activities as related to the project sub-objectives are as follows:-

3.1 Development of sustainability context for coastal aquaculture

3.1.1 Survey - shrimp farm structures, economics and management strategies

The survey work was carried out over 7 geographic areas in Southern Thailand, Pak Phanang, Chian Yai, Satun, Ranod, Ranong, Satun and Krabi. This covered the east and west coasts to encompass different coastal types;- riceland, rubber, mangrove, as well as high and low density farming and even inland farms. Data collection was approached in two ways:-

a) Farm surveys were carried out to derive information regarding the shrimp growout phase of production. Specific courses of investigation dealt with characterization of farms, management strategies and construction and production costs relative to income. Principally the variables covered in this survey were related to farm systems, environment and social issues relevant to the farms. Additional information covered by the survey concerned chemical and antibiotic use during production, management strategies and production difficulties. The management differences that were compared fell into two categories, i) major differences - i.e standard method of production vs lined ponds, recirculation farms, zero water exchange, low salinity farms, inland farms etc. and ii) minor differences such as water exchange, aeration, stocking density etc. The farm management and socio-economic data collected provided information on the principal management and economic factors affecting farm profitability and sustainability. Additional anecdotal sociological information was collected regarding farmer attitudes towards their farms and production methods.

b) Survey of businesses supplying the shrimp farm industry. These surveys aimed to corroborate information obtained from the farms surveyed and also to gain additional information the farmers could not or would not provide. A major part of this was also a costing exercise for the products used in shrimp culture. The products available to the industry are varied, particularly in the field of feed, limes, dolomites, drugs and chemicals. This was also the main source of information relating to credit arrangements for farmers. Informal contacts with the Department of Fisheries and other contacts within the industry provided an additional source of information.

3.1.2 Basic modelling of farm processes

The data collected from these surveys was used to model farm processes such as feed inputs and wastewater production. Economic data collected has allowed the effects of farm size, management strategy and location to be established with respect to production factors. An economic model of the farming systems in different areas was constructed. IOA were assisted in the economic analysis of farm survey data by MRAG.

3.1.3 Assessment of management quality

An important adjunct to the survey programme was to monitor the water quality and state of the pond soil in order to assess the extent to which the farmers management of their ponds were able to maintain a suitable rearing environment within the ponds. Water quality from 120 production ponds in four areas east and west together with the management information allowed characterisation of the systems currently used in Thailand

3.2. Integrated and other systems for low-impact production

3.2.1 Pond liners - effect on water quality

A continuous monitoring programme of production in four ponds at TSFC was established. This compared water and sediment quality between earthen and lined ponds, two of the ponds being normal earthen ponds while the other two were lined with bitumen impregnated geotextile to give valuable information on different water management systems.

3.2.2 Microbial water quality improvement compounds (EM)

The use of microbial compounds to improve water quality in shrimp farms has increased markedly during the time of this project. This is partly due to the increasing adoption of limited water exchange culture systems and partly due to their increasing availability. These compounds variously claim to remove ammonia, reduce organic loadings in the pond water and accumulated sediments and stimulate phytoplankton blooms. The recommended application rates of these products are so low that the effective increase in bacterial concentration is insignificant (0.005%). The general perception of farmers is that addition of these products regularly will prevent water quality deterioration and if there is a water quality problem further addition will rectify this. In practice most farmers use these products on an occasional basis when they feel there is a water quality problem rather than following a programme of use.

3.2.3 Experimental trials on integration of shrimp with bivalve/fish/seaweed culture

A small range of trials was carried out to investigate the potential of incorporating other productive elements into the shrimp culture system, and reduce overall external impact.

a) Three separate rearing trials were performed using green mussels in the concrete raceway system at the TSFC. Initial investigations attempted to quantify the effect of mussels on water quality. This was to provide a baseline against which to compare subsequent effluent treatment experiments. The condition factor of healthy mussels from the coast was also determined to allow comparison with those produced during experimental trials. The first trial utilized mussels that had been transplanted onto ropes, which were suspended in the rearing water. Two subsequent rearing trials used alternative methods of attachment and high rates of water exchange.

b) Seaweed culture in the TSFC ponds was initially extremely successful with a rapid increase in biomass. Subsequently the high biomass produced became fouled with sediment due to the lack of water movement in the ponds and the lines of seaweed eventually became smothered and died.

c) Culture of tilapia spp. was carried out in order to provide experimental material for trials, and to produce effluent water similar to those from shrimp farms. Preliminary investigations demonstrated that this was possible, and that tilapia culture wastes could be used in integration and water treatment trials.

3.3 Water quality management

3.3.1 Database collation and development

The complete water quality data collected by Drs Briggs and Funge-Smith on commercial shrimp farms during ODA Project R4751 has been collated in a specifically designed database at MRAG. This allowed a comprehensive investigation of water quality dynamics.

3.3.2 Analysis of water quality/system interactions

In order to evaluate the impact of farming intensity and seasons on water quality in intensive shrimp ponds, a detailed statistical analysis was carried out on inlet and production pond water quality data from two shrimp farms of different intensity (production of 4 and 9 t ha^{-1} $cycle^{-1}$ respectively).

3.4 Integrated production strategies

3.4.1 Farm economics analysis

Farm economic data collected during the survey work has been tabulated and analyzed jointly by Dr Funge-Smith and Mr. Mark Aeron-Thomas (Economist - MRAG). The treatment of this data has allowed the different areas surveyed to be compared with respect to production inputs and costs and farm characteristics.

3.4.2 Management strategy analysis

This information has been combined with water quality data and existing information modified management strategies can be tested for economic viability. This data was also developed to enable other culture systems to be tested for economic feasibility (*i.e.* partial and full pond linings, recirculation, effective micro-organism use, open and closed systems).

3.4.3 Models for nutrient dynamics

A mathematical model for nitrogen dynamics in intensive aquaculture ponds was developed. The model has been used to evaluate the impact of farming intensity and water management on the concentrations of toxic nitrogen metabolites and phytoplankton in the water column and effluent of intensive farms.

4. PROJECT OUTPUTS

4.1 Development of sustainability context for coastal aquaculture

4.1.1 Results from data collection allowing identification of constraints to sustainability

The identification of constraints to sustainable coastal aquaculture has been performed using shrimp farming as a model. However, as project results confirm, the aquaculture system is only one component within the coastal context. The variation between areas within countries, and countries within a region requires that sustainability be assessed on a case by case basis. The lack of definition of sustainable development requires subjective decisions and identification of priorities. Whilst there is considerable variation between countries and regions with respect to the relative importance of the component issues, the actual issues themselves appear to be fairly consistent. This at least enables a more standardized approach to the assessment of sustainability of coastal aquaculture in general. Key issues emerging from farmer and industry surveys are as follows:

a) <u>Land ownership issues</u>: have an important effect on the manner in which shrimp farming can develop. Ownership of land allows access to capital for farm construction and yet this ability to raise money appears to drive farmers towards rapid returns by intensifying production from their sites. Were a longer term approach possible the requirement for intensive production might be reduced and sustainability enhanced. If land has no formal ownership and is used as a communal resource there is often a serious threat of development by locally influential investors. Small scale artisanal developments can also occur in such areas and if this is of a sufficient scale can also be extremely damaging. Usually artisanal operations lack sufficient capital to develop large areas.

b) Income generation, infrastructural development and economic diversity: the positive influences of shrimp farming are often combined with the general development of a coastal area and not always easily separated. Shrimp farming requires labour and infrastructure, and large scale development cannot occur without basic facilities. Equally, such development may not occur until there is sufficient shrimp farming activity to justify it. The presence of fishing activities is often a starting point for shrimp farming in some areas as basic requirements of road access, ice, equipment and transport are already present (also credit facilities and middlemen). As shrimp farming develops it may become a dominant form of employment in a coastal area. This can lead to the loss of traditional livelihoods, due to loss of resources, and/or because employment opportunities within shrimp farming are greater. While small scale shrimp farmers may still have diverse activities, these no longer form the primary source of income. The principal concern of excessive shrimp farm development is that in becoming the dominant source of income in a coastal area, the whole socio-economic structure may become overly dependent on its success. In the light of the instability of the shrimp industry this is a real concern.

c) Stocking strategy vs. risk: the inherent risks of shrimp farming play an important role in deciding the production and management strategies employed by farmers. The ever present threat of crop failure leads farmers to pursue a production strategy that minimises the risk of loss of money. This takes the form of overstocking such that when an emergency harvest becomes necessary, income obtained can cover production costs up to that point. Price of shrimp is governed by size, and overall income is a function of shrimp price and production weight. Harvesting of shrimp whilst still small will result in a very low price, and so a farmer must ensure that production weight is sufficiently high to maintain income. This leads to overstocking. The paradox is that this probably increases risk of pond failure due to the higher inputs to the system.

d) Environmental quality and its effect on management and disease: to minimise opportunist disease a healthy, good quality rearing environment is important. This also minimises the risk of crop losses. Ideal management approaches involve low stocking densities, good feed management, good influent water quality and good pond management. Unfortunately, the increasing incidence of highly pathogenic viral disease has resulted in these basically sound strategies becoming insufficient. The ability of these diseases to cause serious crop loss even in well managed ponds has forced farmers to adopt alternative strategies. These new methods aim to minimise the risk of introduction of viral disease to ponds and have been adopted at the expense of other important management priorities. This has resulted in production losses in the form of opportunistic diseases, slow growth and poor food conversion ratios. The recent demonstration that these viral diseases could be transmitted in the postlarvae introduced to the ponds has now made all of the previous strategies obsolete. If a disease is introduced at stocking then any attempt to limit its introduction through influent water is nugatory.

e) Viral disease: notwithstanding the above, the importance of good environmental conditions on minimisation of disease should not be ignored, even when confronted with highly pathogenic viral disease. Already, the viral diseases yellowhead and white spot are becoming less pathogenic and more opportunistic in their character. This is rather like the virus MBV, which is endemic in shrimp but is only a problem in ponds when there are environmentally stressful conditions. Currently the ideal strategy to minimise viral diseases and production losses requires: good quality postlarvae, good influent water treatment and good pond environmental management. Dissemination of these techniques is essential for the maintenance of shrimp production in the tropics.

f) Environmental output and impacts: external environmental impacts from shrimp farms can be grouped into land and water effects. The destruction of coastal wetlands for the construction of shrimp farms has serious consequences for the coastal ecosystem and the inhabitants of coastal areas. Whilst it is unlikely that conversion to farms will cease, it is of great importance to be aware of the potential long term affects of this sort of change will have on the coastal zone. Eutrophication and salination of water bodies has occurred as a result of shrimp farming activities. This usually conflicts with agriculture and to some extent with artisanal fisheries. These conflicts are rarely resolved and can only be minimised by compensation mechanisms or well controlled zoning to separate conflicting land uses. The higher income generation potential of shrimp farms and the influence of the investors in these operations does not often result in equitable solutions to these conflicts. This has been the cause of some of the most negative aspects of the industry.

g) Information transfer and inappropriate management techniques: the transfer of knowledge regarding culture and management methods is an important feature of the shrimp industry. The promotion of alternative production strategies is relatively rapid, as farmers' organizations and chemical and feed representatives have a wide information network. However, the vested interests of these organisations can result in the transfer of highly biased information. In the case of feed and chemical companies and their agents the information disseminated is sales oriented and can be extremely misleading. This is especially the case at small shop level where agents are selling on a commission basis. Farmers, desperate for a solution to often incurable problems, are easy targets for the sale of remedial products. A method for the dissemination of sound production practices does not exist, and even where this has been promoted, the competition with other sales oriented sources of information is intense.

As the shrimp farming industry matures, it seems increasingly unlikely that small scale artisanal shrimp farms will survive in their current form. This is due to the high risk nature of their operations. Although small farms are able to survive making very small profit margins the increasing need for good management and production efficiency will strain small farmers' abilities to compete. The ideal shrimp farm seems to be one that has more than five ponds to enable the spreading of risk across the farm. Larger farms are able to employ managers with the relevant skills to produce shrimp and minimize wastage. Very large industrial type farms appear to be fraught with management difficulties and the high investment cost for their construction cost and operation does not enable them to compete effectively with smaller family run operations. The formation of co-operative groups of farmers would allow the rationalization of small farms, construction of good water reservoirs and provide a focus for the dissemination of reliable information.

It is intended to submit an edited version of this study as a chapter for "Recent Advances in Aquaculture". The study draft is appended here as **Appendix V**.

4.1.2 Achievable objectives for the enhancement of coastal aquaculture sustainability

The following tables summarize the issues presented above and present a framework of achievable objectives that can be implemented by all involved or effected by the shrimp industry. These are based on and developed from the work of Stewart (*op cit*). The strategy framework is separated into government, industry and other parties. These divisions should not be viewed as exclusive and dialogue and co-operation between all three groups should be a priority (even if somewhat difficult to achieve).

The issues that affect sustainability of intensive shrimp farming at the enterprise and local resource level are summarised in Tables 1.1 to 1.4 on pages 11-15. These are divided into issues concerning capital inputs, operational inputs, environmental outputs, and social and economic outputs.

Tables 2.1 to 2.3 on pages 16-18 illustrate what could be done at government, industry, and NGO/research/interest groups and other resource user levels to enhance sustainability of shrimp culture and coastal zone development. These are grouped respectively at the level of industry strategies, coastal zone strategies, and financial and educational strategies. All of these are appropriate and potentially achievable, although prioritisation is not attempted, as their relative importance will vary with the national and local context. Any or all of these strategies could achieve benefits.

4.2 Integrated and other systems for low-impact production

4.2.1 Evaluation of different shrimp culture strategies

Table 3 presents key descriptions of different shrimp culture systems, divided according to physical and/or organisational features, and annotates their respective advantages and disadvantages (pages 19 and 20). The following systems have been evaluated further and in more detail for their potential for improving sustainability

4.2.2 Use of bacterial remediation products:

Declining productivity in intensive shrimp culture ponds is a major problem in many SE Asian countries. This is thought to be related to deteriorating quality of inlet water, pond water and pond sediment accompanied by increasing incidence of bacterial and viral disease. In Thailand, farmers are increasingly reluctant to use water exchange as a means of maintaining good water quality in intensive ponds. This is due to the perception that the influent water is the principal source of disease and water quality problems. To minimise water usage, the so called 'closed' or 'semi-closed' pond systems have become commonplace. The use of bacterial water quality remediation products (effective microorganisms - EM) is widespread in the belief that it reduces ammonia and nitrite, organic matter and sediment organic concentration. The study evaluated whether these products have a significant effect upon water quality parameters if pond sediment is present. Results indicate that the addition of EM products to water that is or has been in contact with shrimp pond sediment has no effect whatsoever on ammonia, nitrite and COD reduction. The presence of the sediment appears to be necessary for the removal of inorganic nitrogen. Suppression of bacterial

Table 1(i). Summary of capital input issues influencing shrimp farming and coastal zone sustainability

Input	Feature	Issues
Land	Ownership	• Right to develop often not questioned if land is owned • Un-owned land often low value due to lack of perceived value • Loans/feed credit can be obtained if land title held • Start-up costs lower if land previously owned • Small land packages limit farm size, but may increase farm density
	Rental	• May affect farmers long term outlook • Lack of access to credit due to lack of land title • Use of other forms of credit increases chance of unsustainable practice • Low start-up costs increases opportunity for small operators to enter business • Option for small farmer to make money without personal risk, although land quality may be compromised.
	Site suitability	• Productivity related to environmental quality and access to good soil and water • Production intensity determined by site quality • Unsuitable sites appreciate slowly and may decline in value of farming unsuccessful. • Low farm density desirable • Low disease pool desirable
	Soil type	• Poor soils require greater reclamation costs • Sandy soils suffer from seepage • Mangrove type soils often acidic • Low organic matter content desirable
	Previous use	• Land value (agricultural land high, wetland often low) • Previous use not always sustainable • Subsistence livelihood change with farm development • Resource use diversity may decline with development of farms • Farm size maybe determined by previous land rights/uses
	Alternative use	• Land degradation may affect resource use diversity and other resource users
	Economic value	• Initial investment higher if land has to be bought • High land prices and high interest rates tend to encourage intensive high rate of return practices.
Knowledge/ dissemination of information	Education	• Ability to understand complex management techniques • Ability to evaluate new techniques/ products
	Chemical/feed shops	• Sales oriented advice (often inappropriate) • Interpret complex information and simplify for farmers • Do not provide range of management strategies • Support is infrequent • Solutions are usually remedial not preventative
	Local / indigenous	• Word of mouth transfer of techniques • Farmers modify techniques to suit own beliefs / requirements • Simplification of methods leads to formula farming (non-reactive)
	Experience	• Few farms have long experience • Change is occurring too rapidly to allow farmers to adopt/adapt new techniques
	Government	• Government not involved in extension • Principally support research centres
	Industry	• Seminars • Large company training schemes - sales biased information
Technology	Intensity	• Pond environment • Increasing use of chemical /drugs
	Pond liners, recirculation systems	• Could improve rearing environment • Could reduce environmental impact
	Cost	• Could provide solutions, but initial investment or operational cost too high
Money / Investment	Startup capital	• If money borrowed to develop farm farmers attempt rapid payback • Rapid return of investment encourages high intensity culture
	Source of finance	• Determines interest rate and collateral required • Pressure to pay back greater if moneylenders used
	Operating costs	• Affected by level of intensity • Credit used wherever possible
	Feed costs	• Major part of operating costs • High FCR in intensive system • Feed companies influence can affect policy on shrimp industry • Almost always bought on credit • Failure to pay can result in loss of land • Competition between feed agents results in lower credit rates
Construction costs	Farm size	• Requirement for infrastructure • Little economy of scale
	Geographical region	• Excavation costs, equipment cost, land cost • Pond depth
	System type	• Recirculation requires land for reservoir • Pond linings can double construction cost • Intensive systems require aeration and pumping
	Situation	• Farms in mangrove/ intertidal zone can be tidally flushed • Supratidal farms require pumping
	Level of investment	• Deters small farmers from good construction techniques • Encourages rapid return on investment to avoid incurring interest

Table 1(ii). Summary of operational input issues influencing shrimp farming and coastal zone sustainability

Input	Features	Issues
Seawater/ brackishwater	Quality	• Ability to exchange water • Treatment requirements (settlement, chemical)
	Farm density	• Local water quality conditions • Disease pool
	Salinity	• Ability to use reduced water exchange systems
	Freshwater runoff	• Sediment loadings, agricultural / urban pollution
	Coastal hydrology	• Flushing of embayments / estuaries • Red tides • Disease transmission between farms
	Requirements	• Lack of urban, domestic, agricultural discharges and other shrimp farm effluents
Seed / postlarvae	Quality	• Weak larvae give poor survival at stocking • Viral transmission via postlarvae possible • Overall production low if poor survival at stocking
	Cost	• Stocking density • Low cost larval production techniques may give inferior quality
	Broodstock	• Currently high requirement for wild broodstock • Lack of maturation / spawning requires destructive ablation techniques • Lack of control over genetic improvement or disease transfer
	Transport	• Stressful transport and lack of acclimation can affect survival
	Transfers	• (Viral) Disease / genetic transfer between geographically isolated regions
Feed	Resource use	• All energy in intensive system supplied by feed, semi-intensive systems generate some energy within ponds. • Heavy requirement for imported fishmeal • Local fishmeal poor quality
	FCR	• Too high on most farms • Reduction would improve efficiency and profitability • Feeding control poor, due to poor estimation of pond stock numbers • Low salinity systems give good growth and low FCR
	Assimilation of nutrients	• Relatively low in intensive systems • Nitrogen wasted could be reclaimed by integration of other species
	Cost	• Largest component of operational (variable) costs
Labour	Requirement	• Number of people employed in area can be more than original land use due to higher value of shrimp and associated industries • In extensive systems labour use often lower than original susbsistence livelihoods for same area of land
	Cost	• Minor part of operational cost on farms • Opportunity cost of family labour in small farms
	Origin	• Usually local • Immigrants not tolerated in small farm areas • Large farms able to draw from different areas
Fuel	System type	• High useage due to aeration and water circulation requirements in intensive systems • Required for pumping in water exchange and recirculation systems
	Cost	• Substantial part of operating costs
Chemicals and drugs	System type	• High intensity low water exchange requires high usage • Used as remedial measure in response to problems that occur as a result of bad management • Well managed systems do not require high levels of chemical intervention
	Disinfectants	• Kill bacteria briefly but numbers can re-establish quickly • Ineffective against viruses
	Sales	• Shops often recommend inappropriate / ineffective compounds • Solutions offered may cure symptoms, but do not remedy cause
	Farmer attitude	• Farmers generally aware that drug/chemical use is undesirable, but have no alternative system to use.
Other applications	Zeolites	• Efficacy unproven
	Limes/ dolomites	• Frequently overapplied
	Bacterial products	• Efficacy unproven

Table 1(iii). Summary of environmental output issues influencing shrimp farming and coastal zone sustainability.

Output	Features	Issues
Wastewater	Impact	• Local and coastal eutrophication • Increased sedimentation • May transmit disease between farms and to wild stocks • Red tide occurrence increases • Between farm contamination • May enhance fisheries productivity if loading not excessive
	Improvement	• Liners can reduce sediment and water impacts • Reduced water exchange techniques minimize discharges • Improved feed management reduces wastage • Recirculation techniques can reduce organic matter discharged • Effluent settlement techniques reduce sediment and organic solids • Enhanced bacterial removal of organic matter may improve pond management and reduce discharges
Sediments	Impact	• Serious water quality / production problems in ponds if not properly cleaned • Saline sediments can affect surrounding land and water bodies • Dumping in water courses/inshore coastline causes serious impact • Unsightly
	Improvement	• Pond lining reduces amount of erosion significantly and improves nutrient quality of accumulated sediment • Compaction of pond bottom may reduce erosion
Salination	Social	• Serious conflicts with other coastal resource users esp. agriculture
	Soil	• Salt water intrusion into agricultural soils surounding farms causes crop loss • Overflow from farms causes the same
	Water	• Saline discharges into freshwater bodies can affect irrigation systems and changes ecology of river/canal systems • Low salinity culture systems could contaminate freshwater resources
	Reclamation	• Freshwater flushing • Culture of brackishwater tolerant species in disused ponds
Groundwater removal	Rising saltwater table	• Abstraction of freshwater from boreholes has salinated freshwater resource particularly drinking water
	Subsidence	• In Philippines and Taiwan land subsidence of upto 1-2 m
Loss of habitat	Mangrove	• Large areas exploited for extensive and semi-intensive farming • These areas have subsequently intensified • Loss of habitats for coastal fisheries • Mangroves often already exploited heavily (unsustainably) for wood, farm development can increase pressure • Loss of mangrove can cause coastal erosion
	Agricultural land	• Conversion of sustainable to unsustainable resource use? • Often conversion to shrimp affects surrounding land forcing total conversion of an area
	Remediation	• Re-establishment of degraded mangrove areas around farms • Zoning of shrimp farms to avoid agricultural conflicts
Chemical /drug discharges/ residues	Discharges	• May impact locally but non-lethal to shrimp, therefore unlikely to have acute affect • Biocides are an exception to this
	Residues	• Drug residues have been found but this practice is declining in the face of importing countries' restrictions
	Uncertainty	• The lack of specific knowledge regarding residues and environmental accumulation requires a conservative approach regarding chemical and drug use
Disease	Opportunist	• Diseases of environment and stress • Can be avoided by good management • More common in systems that predispose to bad environmental quality (low water exchange, high intensity)
	Primary pathogens	• Viruses main problem • Initially highly pathogenic and seem to reduce to opportunist type disease after a few years • Transmitted in water and wild stocks and appear to be in seed • May be avoided by good good quality larvae, pond management and low water exchange
	Transfer	• Broodstock and postlarval transfers seem to be most likely route for transmission across large geographical areas • Exotic species introductions another likely route
	Farmer awareness	• Farmer knowledge of disease comes from chemical drug shops and therefore try to cure disease using therapeutants. • Most farmers unaware of the management activities which can presdipose their ponds to disease.
Genetic pollution	Uncertainty	• Transfer of stocks across geographical boundaries may reduce gene pool and effects unknown
	Restocking	• Restocking of fisheries is only demonstrable case of significant changed in genetic character of population.

Table 1(iv) Summary of social and economic output issues influencing shrimp farming and coastal zone sustainability

Output	Features	Issues
Income	Benefits	• Foreign export earnings attractive to investors and governments • Increased income into traditionally poor coastal areas • Some trickle down of income to local inhabitants • Can generate employment • Infrastructural development usually acompanies the development of shrimp farms • Income often far greater than traditional susbsistence livelihoods
	Farm profitability	• Most sensitive to price which in turn relates to shrimp size and state of market • Best strategy for income is production of larger shrimp at lower density • This method is not used due to risk and fear of non-profitability • Profitability sensitive to production level, thus compromise of farmers is to produce a lot of small shrimp to cover costs.
	Farm size	• Ideal farm size is 5-10 ponds, this size spreads risks of pond failure and yet also allows close management by one person.
Employment	Artisanal inhabitants	• Opportunities as pondworkers, harvesters, sorters, packers, pond cleaners, builders
	Feed chemical	• Sales, shops, manufacturing
	Support industries	• Service industries all required to support the workforce • Also additional infrastructural requirements leads to coastal zone development
	Loss of diversity	• Higher income generation and greater profitability than other subsistence livelihoods means there is a greater dependence upon a single industry. • This loss of diversity will be a serious problem if the industry subsequently collapses.
	Reduction of urban migration	• The provision of employment in rural/coastal areas can halt the flow of people to the cities to find employment
Infrastructure development	Industry requirements	• Roads, ice, fuel, electricity, water, labour
	Population requirements	• Administration, food, water, housing
	Job diversity	• Infrastructural development changes the potential for alternative activities. • Roads and ice increase the potential markets for locally produced products. • Administrative development can facilitate business opportunities
Loss of land access	Ownership uncertain	• Displacement of inhabitants by influential investors. • Impacted people are typically the poorest and least empowered of the coastal inhabitants
	Enclosure	• Enclosure of communal resources for farming denies other resource users access
Rising prices		• Increasing wages and income in shrimp farming areas raises food and other commodity prices • Land price rises rapidly marginalising non-landowning inhabitants

Table 1(iv) Summary of social and economic output issues influencing shrimp farming and coastal zone sustainability

Output	Features	Issues
Inequity	Shrimp farmers	• Investors have ability to influence decisions in their favour (e.g. land disputes, illegal farm development, enclosure of common resource, immunity form prosecution) • Small farmers can become wealthier than neighbours who do not/cannot convert to shrimp farming
	Other resource users	• Marginalised groups such as artisanal farmers and fishermen have little ability to redress problems due to lack of collective voice • General lack of recognition due to low economic status.
	Remediation	• Farmers cannot be controlled solely by legislation need to be encouraged to make improvements via collective action • Small farmers organisation should be encouraged • Recogniton of importance of other resource users and their consideration in development strategies
Debt	Loss of land	• Farmers use of land title as collateral for extension of credit can result in loss of land if farm is un-profitable • It is unknown how quickly the ownership of farms is turning over as farmers fail and are replaced by newer investors.
	Interest rates	• High interest rates should encourage low imput system - actually farmers borrow heavily but attempt to repay rapidly, result is high risk management practices
	Remediation	• Improved management • Development of lower risk, lower input system • Debt restructuring by banks/government
Change in community structure	Immigration	• Shrimp farming can attract workers form outside the area which can affect local hierarchies
	Changing influence	• The increased wealth of shrimp farmers can change farmer status within local community. • Conflicts between farmers and non farmers can alter community relations
	Dispossession	• Loss of land due to enclosure or displacement can displace huge numbers of people
Crime	Theft	• High value of crop and relative remoteness of farms makes theft possible • Poaching common on poorly guarded farms • Hijacking has occurred from larger operations
	Other activities	• Illegal activities common due to poor enforcement • Most common is the development of reserved land eg wetland or mangroves • Enclosure of common land usually requires influence

Table 2. Strategic objectives for enhancement of sustainability of shrimp culture

I. Within industry stategies.

	Government	Industry	NGO / research / interest groups / other resource users
Postlarvae and broodstock	• Control broodstock and postlarval import / export especially across geographical boundaries • Provide screening service for broodstock / postlarvae • Hatchery certification	• Improve hatchery survival rates and postlarval quality • Provide / use screening service for broodstock / postlarvae • Non-reliance on wild caught broodstock • Develop domestic broodstock and maturation facilities	• Investigate non-destructive (eyestalk ablation) spawning techniques • Develop reliable screening techniques for broodstock / postlarvae • Develop broodstock maturation techniques • Investigate potential for genetic selection / high health stock
Disease	• Prevent broodstock and postlarval transfers between areas • Provide monitoring / health management service	• Implement effective environmental management within farm • Avoid overstocking / overfeeding • Avoid Excessive farm density • Avoid transmission within / between farms	• Develop rapid screening mechanism for postlarvae and broodstock • Investigate epidemiology of diseases • Rapid transfer of current knowledge of disease risks
Feed	• Apply tariff to feed to encourage better FCR • Control fishmeal imports (limits total production/ encourages less feed intensive culture methods) • Monitor feed quality	• Reduce FCR through effective feed management • Develop diets that are more resource efficient (local protein, natural productivity) • Reduce production intensity	• Investigate alternative feeding regimes that optimise feed efficiency • Promote use of local feedstuffs, improve locally produced fishmeal
Use of chemicals and drugs	• Control market availability of dangerous drugs and chemicals • Provide correct information on chemical/drug usage • Residue testing for export • Certification / licensing of products	• Avoid use of hazardous chemicals / drugs • Adopt best management policies to reduce requirement for chemicals/drugs • Avoid prophylactic use	• Investigate potential impacts of chemicals and drugs • Provide non-market lead information regarding drugs/chemicals • Promote awareness of potential hazards of overuse \ abuse

Table 2. Strategic objectives for enhancement of sustainability of shrimp culture

II. Coastal zone strategies.

	Government	Industry	NGO / research / interest groups / other resource users
Land	• Develop zoning strategy • Intervene to prevent excessive development when market or public good threatens sustainability • Implement land tenure / ownership / community ownership • Protect communally exploited resources • Implement farm registration • Monitor development of farms	• Avoid unsuitable areas/soil (*e.g.* mangrove soils, wetlands, productive agricultural land) • Rental discourages long term approach	• Designation and protection of community resources (*e.g.* forest, fishery, freshwater, access) • Disseminate sustainable alternative land uses
Environmental management	• Limit farm density through zoning restrictions • Engineering works to provide rational influent and effluent sources • Promote use of effluent storage ponds • Institute compensation mechanism for cases of adverse impact (local and provincial level) • Loans for farm wastewater treatment / improvement • Monitor impacts	• Minimize wastes by good pond environmental management • Minimize overfeeding / chemical / drug use • Appropriate farm design (include reservoirs, settlement ponds) • Fallow sites if possible • Adopt low impact systems (*e.g.* pond lining, storage of effluent, low water exchange systems, recirculation) • Appropriate site selection	• Develop appropriate wastewater treatment technology • Investigate alternative low impact systems • Other users of water resource require support if resource quality is degraded • Improve self-regulation through knowledge of potential impacts / self-pollution • Monitor impacts
Influent water	• Monitor coastal impacts on water quality (urban, industrial, agricultural, aquacultural) • Provide suitable influent water canal systems for small farmer aggregations	• Monitor influent water quality • Use influent water storage / treatment ponds • Avoid wastewater discharge into (or close to) influent water sources	• Monitor coastal water quality • Monitor other users of coastal water resource
Other resource uses	• Value alternative resource uses appropriately during formulation of coastal zone management strategy • Encourage diverse usage of coastal zone resources • Improve rights of minority / marginalized groups with respect to land title and access. • Involve all resource users in decision making process	• Avoid conflict with other coastal resource users • Avoid salination of freshwater resources • Do not degrade agricultural land • Do not develop in mangrove or alter mangrove hydrology	• Empowerment of interest groups *e.g.* small scale fishing communities, rice farmers, artisanal coastal communities • Promotion of alternative sustainable livelihoods to shrimp farming • Assistance to impacted communities • Monitor impacts on coastal resource users / communities

Table 2. Strategic objectives for enhancement of sustainability of shrimp culture

III. Financial and educational strategies

	Government	Industry	NGO / research / interest groups / other resource users
Capital / money / investment debt	• Provide soft loan facilities to small farmers • Support alternative coastal resource uses to maintain diversity • Restructure debts of small farmers to enable diversification out of shrimp culture • Support rehabilitation of disused / degraded culture areas	• Reduce input costs (especially: feed, chemicals, fuel) • Do not seek rapid payback / high rate of return • Avoid using excessive credit • Rehabilitation of disused / degraded culture areas using new culture systems / alternative species	• Monitor debt in coastal communities • Emphasise economic risk / lack of sustainability of pursuing rapid / excessive return on investment • Promote low input culture systems for artisanal inhabitants / failed shrimp farms
Knowledge	• Support / provide training and extension • Publicise potential financial / environmental / social risks of unsustainable culture practice. • Provide local training centres	• Provide training and extension (usually vested interest / patronage) • Liaison with government and non-government organisations so that research and information dissemination is appropriate to the industry's needs	• Training in non-vested interest sustainable techniques • Dissemination of information in understandable form • Adapt complex sustainable culture techniques for small farmer application

Table 3. Descriptions of shrimp culture systems - advantages and disadvantages

System type	Advantages	Disadvantages	Comments
Open (high water exchange)	• Good water quality management relatively easy • May introduce supplemental feed • Can achieve fast growth and good FCR • High water exchange rate may allow removal of accumulated sediments via central drain	• Risk of introduction of viral organisms with influent water • Influent water may be polluted by other farms/resource users • High water pumping costs • Reduced requirement for aeration • Effluent water high volume may impact on receiving waters	• Original farming system • Reliable provided influent water is of good quality
Semi-closed (low water exchange)	• Reduces reliance on good external water quality • May reduce opportunity of viral disease entry to farm • Reduces pumping costs • Reduces cost of influent water treatment	• Water quality may deteriorate • Growth may be slower • High cost of pond water treatment • May have problem with high salinity • Freshwater abstraction used • High density phytoplankton bloom common	• Common in Thailand , no water exchange for first month and minimal changes thereafter. Increased water exchange in last month of production
Closed (zero water exchange)	• Minimises risk of viral disease entry to farm via influent water • Pond filled once during cycle and occasional top-ups for evaporation and seepage • Minimal water pumping costs • Influent water treatment costs low • Reduced impact on receiving waters (only during harvest)	• Slow growth and often poor FCR • Opportunist disease frequent • Poor water quality usual • High organic/bacterial loadings • High ammonia concentrations • High cost of pond water treatment • Aeration costs high • Evaporation can cause high salinity • Freshwater abstraction used • High density phytoplankton bloom common	• Adopted in Thailand but farms suffered from opportunist disease problems and economic difficulties due to poor growth and FCR. • Ammonia concentrations above 3.00 $mg.l^{-1}$ frequently encountered. • Most farms attempt semi-closed system now.
Lined	• No erosion of pond bottom and pond walls • Very little sediment accumulation • High water content of accumulated sediment allows removal by pumping or central drains • Sediment removal may allow reduced water exchange regimes and improved water quality • Possibility of quick turn around between crops • Good potential for integration with other species due to lower sediment accumulation	• Expensive ($1.50-3.00.$m^2$) can double construction costs • Service life may not be long enough • May not retain feed well, poor FCR results • May not have same microflora as earth pond so little supplemental feeding • Phytoplankton bloom may be unstable during early part of production • Aggressive reduced conditions may occur beneath the liner if drainage inadequate • Will deteriorate rapidly if exposed to sunlight for too long • Liners may float	• Liner types include: pvc or polyethylene 0.2-1.0 mm thick, bitumen impregnated geotextile, High density polyethylene (HDPE), laterite earth • Lining costs estimated at 40 - 80,000 $TB.rai^{-1}$, (250,000 - 500,000 $TB.ha^{-1}$)

Table 3. Descriptions of shrimp culture systems - advantages and disadvantages (cont.)

System type	Advantages	Disadvantages	Comments
Recirculation and integrated farms	• Can minimize salinity fluctuations in estuarine areas • Reduces dependence on external water quality • Enables closer environmental control within farm. • Potential for integration with other species • Reduced environmental impact • Potential for integration with fish species such as mullet or tilapia	• High water pumping costs around system • High requirement for settling pond areas (>50%) • Not feasible for small farmers • Rapid disease transmission within system • Problem with high salinities if brackishwater not used • Fouling with solids prevents culture of many organisms	• Not used commercially • Engineering of system complex and high cost
Low salinity culture	• Fast growth rates • Good FCR • Shorter growout period (90 days) • One crop per year effectively fallows site for 8 months, lowering in pond environmental degradation • In systems using hypersaline water risk of viral disease transmission minimal	• Shrimp harvested at small size • Cannot farm during wet seasons • Salinity can become critically low • Blue-green algae may give off flavour • Salination of inland areas • Only one crop a year • Water exchange not possible therefore water quality may be a problem if feed application excessive/pond overstocked	• Can be situated in low salinity parts of estuarine system or inland . • Inland farms use hypersaline water transported from salt farms by truck • Ideal stocking density $<30.m^{-2}$
Seawater pumping and drainage canal rationalization	• Rationalised water supplies and drainage for farming areas • May allow treatment of efluents before discharge • Effluent water discharged 2 km offshore avoids longshore drift effects • Does not require action by farmers	• High cost large scale government project • Only suitable where there are existing water channels • Runoff during monsoon will overload system • Lack of gradient in coastal areas prevents effective drainage • Only affects small numbers of farms • Cannot be used in areas where farm density is low	• Government instituted projects as part of coastal shrimp farm rationalisation plan. • Cost estimated at 117,132 $TB.rai^{-1}$ (TB 732,075 $TB.ha^{-1}$) • Not yet widescale • Unproven efficacy
Franchise schemes	• Small farmers have access to large farm type infrastructural support • Rationalised farm design and influent reservoirs • Technical support available • Company underwrites loans to farmers • If farmer insolvent, company manages pond to pay off loan, land remains a possession of the farmer.	• Farmers must purchase seed and feed from the company • Company buys shrimp below market price (approximately TB $10.kg^{-1}$) • Fixed rate for water and power costs irrespective of production method • Large numbers of farmers difficult to organise and difficult to resolve disputes	• Aquastar company in southern Thailand
Nursery	• Production of on-grown strong juveniles for stocking into ponds • Reduced growout time in pond may lower risks in closed type system • Reduces stocking density requirement due to better survival • Potential for larger farms to nurse own larvae on-site • Potential for small farmers to diversify into nursery operation • Larger animals allows better viral disease screening	• More expensive due to on-growing costs • Transfer may be stressful, and more difficult due to larger size of animals • Small farmers need to buy from local nursery	• Nursery operations are rare, possibly as a result of poor profitability • This situation may change as health and disease status of postlarval supply becomes more critical

activity through the use of antibiotics appears to prevent the reduction of inorganic nitrogen. Addition of sugar appears to cause rapid ammonia-N removal, especially if high concentrations of EM are used, but the effect is not sustained. It is concluded that a suitable carbon source might one of the rate limiting factors in inorganic nitrogen reduction in shrimp ponds. EM products are more likely to be of use in systems where sediments are lacking or minimal *e.g.* lined ponds and hatcheries. This work has been written up as Funge-Smith, S.J. and Hawthorn S, The Effect of Microbial Remediation Products on Water Quality in the Presence of Shrimp Pond Sediments for publication **(Appendix III)** and some of the work was presented by Dr Funge-Smith at the World Aquaculture Society Conference in Bangkok in January 1996.

4.2.3 Integration of other species into shrimp culture systems:

Results from this work in the first year of the project indicated that high sediment loadings contraindicated successful culture of mussels and seaweed. Anecdotal reports suggests that such integration systems can work and the possibility of their use in conjunction with lined ponds where the nutrient content of the effluent is much higher because of the reduced contribution from the pond bottom to the effluent could be particularly worthy of investigation.

4.3 Water quality management

4.3.1 Database development

The water quality data collected during ODA Project R4751 are available in a relational database.

4.3.2, Statistical analysis of water quality data

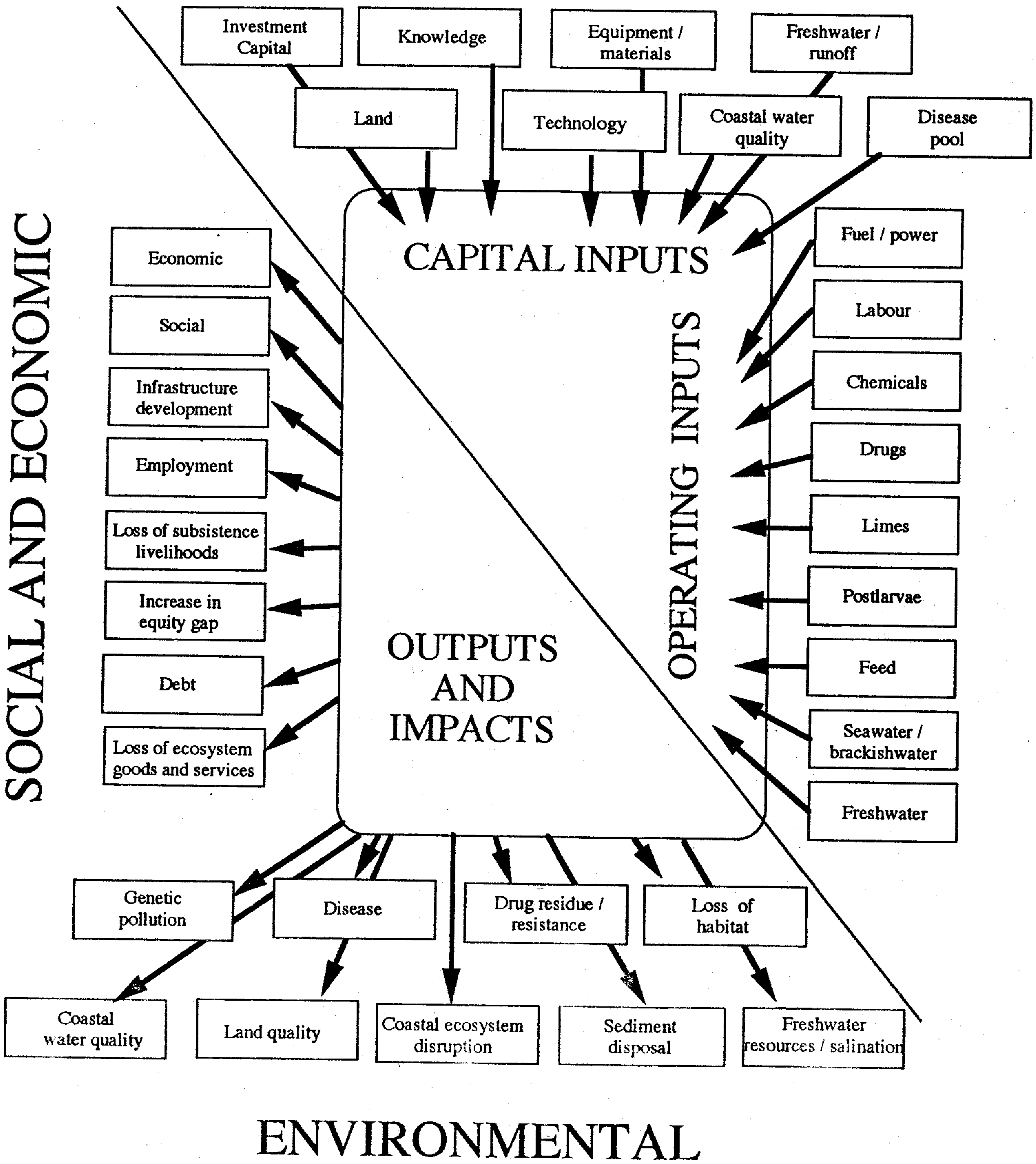
The detailed statistical analysis carried out on inlet and production pond water quality data from two shrimp farms of different intensity (production of 4 and 9 t ha^{-1} $cycle^{-1}$ respectively) in order to evaluate of the impact of farming intensity and seasons on water quality in intensive shrimp ponds showed that significant intensity-related differences in water quality occurred in many parameters during the final period of the production cycle, but rarely in the early or middle period of the cycle. Water quality parameters in the final period of the cycle were analysed further for effects of production intensity and season.

a) Season: as defined by the monsoon period, was found to have a major impact on water quality. Season caused significant variation in almost all parameters in the farm water inlets. In the production ponds, season was more often a source of significant variation than production intensity and season often explained more of the total variation in water quality than intensity.

b) Production cycle: significant trends in water quality parameters over the production cycle were rare in the low intensity farm, but occurred in more parameters in the high intensity farm.

Results suggest that water quality in the ponds is largely independent of intensity, up to a threshold which can be understood as the carrying capacity of the pond ecosystem. The low

Fig. 1. Sustainability features of intensive shrimp farming



from Stewart (1995)

organic loadings were not significantly different from low water exchange systems (6.0 - 7.7 mg.O_2l^{-1}). This suggests that sedimentation and stabilization of the organic matter in shrimp ponds is an important process in determining pond water quality.

The effects of pond lining on sediment quality was also investigated. Accumulated sediment in lined ponds has a significantly higher ammonia, water and organic content, however, the overall amount of sediment accumulated is very low. The physical characteristics of sediments from lined and unlined ponds reveals that the sediment from lined ponds can be easily removed by pumping during production. This has significant management implications for low water exchange systems. Total effluent nutrient loadings were significantly lower in the zero water exchange system than the other systems studied. This shows the potential for minimising environmental impact through reduced water exchange. There is a need for further development of management strategies to allow the maintenance of a healthy rearing environment whilst reducing effluent impact. This work has been written up as a paper, Funge-Smith, S.J. Water and Sediment Quality in Different Intensive Shrimp Culture Systems in Southern Thailand (to be submitted to Aquaculture), **Appendix I**

4.4.3 Water quality modelling

Various parameters were examined in order to determine the possible existence of critical inter-relationships which could then form the basis of management tools. The dynamics of nitrogen components in the water column and effluent of intensive aquaculture ponds were investigated using a mathematical model. In the model, excretion by animals and mineralisation of wasted feed lead to ammonia input into the water column. Assimilation by phytoplankton and nitrification transform ammonia into particulate (organic) nitrogen or nitrite/nitrate. Nitrogen is lost from the water column through sedimentation of particulate nitrogen, volatilisation of unionised ammonia, and discharge of both particulate and dissolved nitrogen during water exchange.

The best water management strategy to limit pond concentrations of dissolved nitrogen (ammonia and nitrite/nitrate) was found to depend strongly on stocking density. At moderate stocking densities dissolved nitrogen can be maintained at low levels through phytoplankton assimilation if water exchange is low, or through dilution if water exchange is very high. The highest dissolved nitrogen levels occur at intermediate water exchange rates, which limit total primary production (and nitrogen assimilation) but are insufficient to remove excess dissolved nitrogen. At high stocking densities, ammonia input exceeds the phytoplankton assimilation capacity, resulting in high levels of dissolved nitrogen which are progressively reduced with increasing water exchange. Total nitrogen discharge increases continuously with the water exchange rate. At low exchange rates, most nitrogen is discharged in particulate form, while at high exchange rates discharge is primarily of the dissolved form.

This work has been written up and presented as:-

Lorenzen, K., Struve, J. and Cowan, V. J. Impact of stocking density and water management on nitrogen dynamics in intensive pond culture: a mathematical model applied to Thai commercial shrimp farms. Submitted to *Aquaculture Research*. **Appendix VIII.**

4.4.4 Economic model of shrimp production

The economics of intensive shrimp farms in southern Thailand were studied as part of a wider study of sustainability in intensive shrimp farming. Over 100 Farms in six provinces were surveyed for management, economic and socio-economic data. Additional information was gathered from feed and chemical retailers in the provinces surveyed. Of the farms surveyed 37% used their own money to finance their operation and 24 % had used their own money and borrowed the remainder. The majority of farms used credit for their feed costs. The breakdown of production costs revealed that feed (51 %), seed (14 %), fuel (11 %), constituted the majority of variable costs. Shrimp price was found to have the most significant effect on overall profitability, a 10% change in price changing profitability by 73%. Shrimp production was the second most important factor affecting profit, a 10% change affecting profit by 47%. It is concluded that producing fewer large shrimp is the most profitable strategy for farms. Small farmers fearing economic losses do not pursue this strategy and overstocking together with production of small shrimp is the most common management method. The effect of region, farm size and pond size on farm economics was also studied. There were significant regional differences in shrimp price, shrimp production and some operational costs. Farm size significantly affected equipment costs and net revenue. It is proposed that the optimal farm size is approximately 5 - 10 ponds. Pond size significantly affected net revenue and total revenue. This was concluded to be an effect of larger farms having larger ponds and better production. Improvement of food conversion ratios, water management and development of healthy seedstock are recommended as priorities for the industry to become more sustainable.

This work has been written up for publication as:

Funge-Smith, S.J. and Aeron-Thomas, M. The Economic Factors and risks influencing the Sustainability of Thai Intensive Shrimp Farms. **Appendix II**

5. CONTRIBUTION OF OUTPUTS

5.1 Contribution to ODA's developmental goals

The project has made important steps to identify the impacts of aquaculture development in the coastal zone and identified the key constraints to sustainability. The previous project R4751 concentrated on environmental problems and potential solutions. This project built on that knowledge in two main pathways 1) to understand the more wide ranging constraints from the socio-economics as well s the environmental and management viewpoints so that solutions offered are relevant 2) to construct models of systems as built up from the previous work (Project 4751) to further help clarification of limits, both biological/environmental and management within the system. The complexity of the system is indisputable but such models highlight where further information can be collected to make the system more manageable. It also indicates which parts of the system are most sensitive to change and so can provide a very useful management tool.

Another aspect the socio-economics survey has given hard facts to in the area of disease control. It is known that poor conditions will lead to disease in shrimp ponds (not withstanding the additional dimension of viral disease); what has not been so clearly highlighted before is what forces are leading farmers to adopt practices that are inherently likely to lead to the disease problem they fear. Understanding these forces better can lead the way to showing management practices that will both alleviate the fears and the problems.

5.2 Identified promotion pathways

This project and the previous one (R4751) have generated a lot of interest and there have been many approaches from International organisations such as DANCED and DANIDA as well as NGO's and other interested parties. During survey work at farms, discussion of specific and general problems have taken place together with informal pond side training to small farmers. Many of the identified promotion pathways have been established during the project with many outlets for information transfer being established. These have included:-

Conferences/Workshops

a) Dr Funge-Smith attended the "Annual Forum Reporting on the Southern Thai Environment" in Hatyai, October 12th 1995.

b) Dr. Funge-Smith has been invited to present a plenary lecture entitled ' Pond Nutrient Dynamics' at the Second International Conference on the culture of Penaeid Prawns and Shrimps (May 1996) in Iloilo City in 1996.

c) Dr. Funge-Smith taught for a total of 4 weeks at two Shrimp Health Management Workshops held at AAHRI, Bangkok in January and July 1995.

d) Dr. Funge-Smith was invited to attend a meeting of the Marine Science and Technology Directorate to discuss their proposed World Bank projects for coastal zone management, May 1995.

e) During the project training lectures to shrimp farmers have been provided on three separate occasions. These lectures were delivered in Thai by Dr Funge-Smith and focused on the results of the current and previous ODA project.

f) Three lectures were delivered to the BSc course at the Tinsulanonda Songkhla Fisheries College on the subject of farm water quality management and sustainable methods of shrimp culture. These lectures were presented in Thai.

g) Dr. Funge-Smith presented the results of the research into the effects of microbial water quality improvement compounds in an oral paper at the World Aquaculture Society conference in Bangkok (January 1996) (referenced below).

Publications and Reports

The main outlet pathway identified has been through publications and the work presented here is already written up ready for publication or already submitted for publication. The complete list of publications from this project is noted here.

complete list of publications from this project is noted here.

a) Funge-Smith, S.J.,(in manuscript) Water and sediment quality in different intensive shrimp culture systems in southern Thailand (to be submitted to Aquaculture) (Appendix I)

b) Funge-Smith, S.J. and Aeron-Thomas, M.,(in manuscript), The Economic Factors and risks influencing the Sustainability of Thai Intensive Shrimp Farms. (to be submitted to Ambio) (Appendix II)

c) Funge-Smith S.J. and Hawthorn S., (in manuscript), The Effect of Microbial Remediation Products on Water Quality in the Presence of Shrimp Pond Sediments. (to be submitted to Aquaculture Research) (Appendix III)

d) Funge-Smith S.J. and Briggs, M.R.P. (in manuscript) Intensive Shrimp Pond Nutrient Budgets - Implications for Sustainability (to be presented at the Second International Conference on the culture of Penaeid Prawns and Shrimps (May 1996) in Iloilo City.(to be published in Conference proceedings) (Appendix IV)

e) Funge-Smith S.J., and Stewart, J.A.,(in manuscript) Coastal Aquaculture: Identification of social, economic and environmental constraints to sustainability with reference to shrimp culture. (Appendix V)

f) Cowan, V J, Lorenzen, K and Funge-Smith, S J (subm.) Impact of culture intensity and season on water quality in Thai commercial shrimp farms. Submitted to *Aquaculture Research.* (Appendix VI)

g) Cowan, V J, Struve, J and Lorenzen, K (1996). A brief review of water quality modelling in aquaculture. Internal Project Report. (Appendix VII)

h) Lorenzen, K, Struve, J and Cowan, V J (subm.) Impact of stocking density and water management on nitrogen dynamics in intensive pond culture: a mathematical model applied to Thai commercial shrimp farms. Submitted to *Aquaculture Research.* (Appendix VIII)

Dr. Funge-Smith also contributed new chapters in the writing of the second edition of 'Shrimp Health Management', the training manual accompanying the AAHRI workshops. Chanratchakool, P. Turnbull, J.F., Funge-Smith S. and Lisuwan, C. 1995. Health Management in Shrimp Ponds (second edition). Aquatic Animal Health Research Institute, 111pp.

5.3 Priorities for Follow-Up

The socio-economics survey has allowed a framework to be constructed for assessing sustainability factors in shrimp farming. It would be useful to market test these in different geographic and cultural areas to test the transferability of the approach. This approach is intended to be transferable between regions but the relative importance of different components will be area specific. It is important that this approach be validated in other shrimp farming countries.

Where constraints are clearly identified, mechanisms need to be established to rid the systems of these. Many of the poor management strategies follow from a lack of confidence at several stages in the system. For example, having a better quality of post-larvae would increase confidence initially and from this it could be possible to encourage farmers to adopt strategies to produce fewer larger shrimp and in the process incur less risk from other sources such as the over stocking forced on them by lack of confidence in the post-larvae. Many such examples could be drawn from the results of this study.

There is a clear need for advice free from vested commercial interest to be available to farmers. This is quite a complex issue. For example, while it can be seen from the economic analysis that growing larger shrimp can improve financial returns from ponds and that producing these with the lower stocking densities required, would impose less environmental problems, the strategy to allow implementation of such an approach needs to be carefully investigated for each geographic location. Possibly the greatest need for the follow-up to this project is to ensure that this appreciation of the complexity of the system is as widely disseminated as possible.

Water quality management has been identified as one of the key issues in the sustainability of coastal aquaculture. The project has demonstrated the potential of quantitative analysis and modelling to improve the conceptual understanding water quality management, and to quantitatively evaluate management options. Two areas of water quality management require urgent attention:

(i) Water quality management in closed ponds (no-water-exchange-systems).

(ii) Management of recirculation systems, particularly those involving biological water treatment.

A comprehensive approach integrating modelling, experimentation and quantitative analysis is expected to result in rapid progress in both areas. The present model should be expanded to include other water quality parameters and to explicitly consider other management actions such as aeration and circulation. Management options should be explored using the model and key uncertainties (gaps in knowledge) identified. Experiments should be designed specifically to address the identified uncertainties.

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