Final Report to the Overseas Development Administration

DEVELOPMENT OF STRATEGIES FOR SUSTAINABLE SHRIMP FARMING

Research Project R4751

Institute of Aquaculture
University of Stirling
Stirling FK9 4LA

Period of report: April 1991 - April 1994

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Appendices

1. Briggs, M.R.P. 1993. Status, problems and solutions for a sustainable shrimp culture industry with special reference to Thailand. *Unpublished report to the ODA*. 41 pp.

2. Briggs, M.R.P. and Funge-Smith, S.J. (submitted to *Aquaculture International*). Unsustainable shrimp culture - causes and potential solutions from experience in Thailand.

3. Briggs, M.R.P. 1992. Four years of ODA-supported collaboration between the Tinsulanonda Songkhla Fisheries College, Thailand and the Institute of Aquaculture. Article in *Aquaculture News*, **14,** July, 1992, 1 p.

4. Briggs, M.R.P. and Funge-Smith, S.J. 1994. Shrimp farm environmental quality - its relationship to sustainability. *Aquaculture News* **17,** 1994. 1 p.

5. Briggs, M.R.P. and Brown, J.H. 1991. Intensive rearing of post-larval *Penaeus monodon* Fabricius in concrete nursery tanks. Paper presented at the *22nd World Aquaculture Society Conference,* San Juan, Puerto Rico. June, 1991, 19 pp.

6. Briggs, M.R.P. 1992. A stress test for determining vigour of post-larval *Penaeus monodon* Fabricius. *Aquaculture and Fisheries Management* **23,** 511-515.

7. Briggs, M.R.P. and Funge-Smith, S.J. (in press). A nutrient budget of some intensive marine shrimp ponds in Thailand. *Aquaculture and Fisheries Management.*

8. Funge-Smith, S.J. and Briggs, M.R.P. (in prep.). The origin and fate of solids and suspended solids in intensive marine shrimp ponds in Thailand.

9. Briggs, M.R.P. 1994. Nutrient modelling in sustainable shrimp farming. Lecture presented at the *AAHRI/ODA Shrimp Health Management Workshop,* Aquatic animal Health Research Institute, Kasetsart University Campus, Bangkok, 11-18 January, 1994.

10. Funge-Smith, S.J. and Briggs, M.R.P. (in prep.). The organic composition of soil and accumulated sediments in intensive marine shrimp ponds in Thailand.

11. Funge-Smith, S.J. and Briggs, M.R.P. (submitted to *Aquaculture*) Water quality and nutrient discharge of intensive marine shrimp ponds in Thailand and their relationships to pond productivity.

12. Briggs, M.R.P. and Funge-Smith, S.J. 1993. Macroalgae in aquaculture: an overview and their possible roles in shrimp culture. In. *Proceedings of the Conference on Marine Biotechnology in the Asia Pacific Region. Bangkok, Thailand.* 16-20 November 1993. 5 pp.

13. Funge-Smith, S.J. and Briggs, M.R.P. (in prep.). Growth and ammonia removal by *Gracilaria spp.* in brackishwater and intensive shrimp farm influents and effluents.

14. Briggs, M.R.P. and Funge-Smith, S.J. (submitted to *Aquaculture and Fisheries Management*). The effects of zeolites and other alumino-silicate clays on water quality at various salinities.

15. Briggs, M.R.P. 1994. The effectiveness of zeolites and other aluminosilicate clays in reducing the level of organic nutrients in water of various salinities. *AAHRI Newsletter,* June, 1994, 1 p.

16. Briggs, M.R.P., Brown, J.H. and Fox, C.J. 1993. The effect of dietary lipid and lecithin levels on the growth, survival, feeding efficiency, production and carcass composition of post-larval *Penaeus monodon* Fabricius. *Aquaculture and Fisheries Management* **25**, 1-16.

17. Briggs, M.R.P., Fox, C.J. and Brown, J.H. 1994. (Submitted to *Aquaculture and Fisheries Management*) The effects of dietary carbohydrate and lipid levels and their ratio on performance, carcass composition, midgut gland amylase activity, diet digestibility and histology in post-larval *Penaeus monodon* Fabricius.

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19. Hartati, R and Briggs, M.R.P. 1993. The effect of feeding attractants on the behaviour and performance of juvenile *Penaeus monodon* Fabricius. *Aquaculture and Fisheries Management* **24**, 613-624.

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23. Briggs, M.R.P. and Funge-Smith, S.J. (submitted to *Aquaculture and Fisheries Management*). The potential of *Gracilaria spp.* meal for supplementation of diets for juvenile *Penaeus monodon* Fabricius.

ODA Report for Research Project R4751

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1. Objectives of the project - [revised August 1992]

Three broad but interlinking objective areas are proposed, as follows:

1a Production, management and impact:

i To examine existing farming and management practices, with particular emphasis on stocking, mortality and yield, feed use and quality, water/substrate management,

ii In selected locations, to outline social and economic profiles, describing practices and attitudes of range of shrimp farmers at varying intensity levels;

iii To describe aquaculture/community relationships in the study location; define resource levels, actual/potential impacts;

1b Systems and environment:

i To review stocking practices and evaluate the potential of early rearing/nursery systems for improving early stage survival and quality of ongrown stock;

ii Examine nutrient exchanges between water and substrate, investigate mechanisms for declining productivity in more intensive systems; assess means (including integration/ polyculture) of improving internal nutrient cycling and reducing discharge/wastage to receiving waters; through field analyses backed up by laboratory and model/ microcosm studies.

iii Examine linkages between stocking and management, microbial communities in shrimp ponds, and the potential fates and impact of antibiotic and other treatments.

1c Inputs and conversion:

i Investigate contribution of pond biota to productivity; their role in mineral and vitamin supply; optimising systems towards reducing expense of external components;

ii Examine the potential to reduce production costs using indigenous feed materials, alternative protein sources and protein-sparing through use of carbohydrates; examine ways to reduce wastage through improving palatability/digestibility; through a combination of laboratory and field work.

Contributing personnel throughout project

Academic staff

Dr Janet H. Brown, University funded Research Lecturer, Project Leader
Dr Clive Fox, ODA funded Research Fellow - until end of March 1992
Mr Matt Briggs, ODA funded Research Assistant
Dr Simon Funge-Smith, ODA funded Research Fellow from April 1992
Mr Patrick Blow, temporarily funded to complete Dr Fox's project

Support staff

Mr Willy Hamilton, ODA funded technician, part-time
Ms Lorraine Wilson, University funded technician
Mr Fraser Griffiths, technician at Machrihanish
Mr David Nickell, temporary technician for chemical analyses

Research students working with Prawn Team

Ms Marlie MacLean, Part-time, University funded (EC funding from March 1989)-until February 1992
Mr M. Latif, ADB funded PhD student from Bangladesh (Dr J.H.Brown)
Ms Ana Rocque, EC funded PhD student (from December 1991) (Dr J.H.Brown with Dr J. Turnbull)
Mr Melchor Tayamen, AADCP funded student, Bureau of Fisheries and Aquatic Resources, National freshwater fisheries technology research center, Munoz, Nuevia Ecija, Dept. of Agriculture, The Philippines.
Mr Alvaro Armas, EC funded student from Nicaragua
Ms Maria Garcia, British Council funded MSc student from Ecuador

Visitors to Prawn Unit during the project.
Ms Retno Hartati, Academic visitor from Universitas Diponegoro, Semarang, Indonesia.
Mr Roberto Retamales, Universidad Tecnica de Manabi, Instituto de Acuicultura, Ecuador
Dr Shivananda Murthy, University of Mangalore, India

2. Work carried out during the project

Thailand is currently the largest producer of cultured shrimp in the world. Thailand has achieved this production by intensifying its existing shrimp culture industry through the transfer of Taiwanese technology. The repeated collapse of the Taiwanese industry over the past 7 years has demonstrated the unsustainability of this culture system. Increasing signs of unsustainability in Thailand due to overintensive culture have provided the opportunity to study the underlying causes of declining productivity and farm failure. This is of crucial importance as other developing countries are increasingly adopting these Taiwanese/Thai style culture techniques. The historic unsustainability of this cash crop approach to shrimp farming demands the adoption of new methods of shrimp production which can be integrated into the sustainable development of coastal resources. This has provided the rationale for this project.

2.1,a Production, management and impact

2.1,a,i, The management practices of the farms studied (as discussed in section 2.1,b) during the course of this project were recorded and the information is presented. This covered the management of production intensity, water quality, sediment quality, feeding and water usage. The interrelationship of these factors was discussed in terms of the sustainability of the intensive shrimp production system.

2.1,a,ii, A survey of farm management practices was performed by NACA/ODA in the areas where the majority of the research for this project was performed. The wider perspective this information provided was incorporated into the more specific farm studies discussed in section 2.1,b. To this was added additional farming and socio-economic information gathered during liaison meetings with the Aquatic Animal Health Research Institute (AAHRI), the Network of Aquaculture Centres in Asia (NACA), the National Institute of Coastal Aquaculture (NICA), the Asian Wetland Bureau (AWB), the Coastal Resources Institute (CORIN), Tinsulanonda Songkhla Fisheries College (TSFC), the Asian Institute of Technology (AIT), Prince of Songkhla University (PSU), Srinakarinwirot University, DANIDA, and commercial organisations Aquastar and CP as well as local farmers, fishery stations, VSO, CUSO and other NGOs. This information was not gathered as a survey to avoid replication of the NACA/ODA survey. It was however, incorporated into the publications and presentations produced during this project. The information from the field was supported by a comprehensive review of the literature regarding the sustainability of shrimp farming.

2.1,a,iii, The relationship between shrimp farming and coastal resource use was reviewed via the literature and the liaisons described above. This covered the economic and socio-economic interactions with respect to the relative importance of sustainable shrimp culture in the coastal environment. Implications of the rapid decline in shrimp production per unit area in over-exploited areas were discussed and the potential for alternative methods of production and waste reduction have been suggested.

2.1,b Systems and Environment

2.1,b,i, To avoid early mortality due to stressful conditions in the growout ponds, the nursery rearing of post-larval shrimp was studied with respect to its ability to provide large, healthy seed for stocking. This technique showed poor feasibility at an early stage of investigation, necessitating a change in emphasis to concentrate on management of the production pond environment in order to achieve high growth, survival and production during ongrowing.

2.1,b,ii,1, An 18 month water and sediment quality monitoring programme was instituted at three intensive shrimp production farms. These farms contained ponds of different age and stocked at different densities. The nutrient and solids flow through these intensive shrimp farm systems was studied and presented in the form of nutrient and solids budgets. The range of management techniques employed on these farms has allowed the identification of some of the critical parameters in the unsustainable production of shrimp. This has allowed the modelling of wastage through these systems, estimation of the potential impact of such systems on coastal nutrient loadings, and possible methods for its minimization. The feasibility of integrated production systems, land reclamation and polyculture were also considered.

2.1,b,ii,2, Declining productivity was observed in all the farms studied and was attributable to long term chronic stress due to poor water quality. This was demonstrated by the water quality monitoring programme which revealed that poor water quality and hence stress were attributable to overstocking of production ponds. Quantification of nutrient export from intensive shrimp farms was further investigated with respect to the potential for culture of seaweed (*Gracilaria spp.*). Studies as to the feasibility of seaweed integration into shrimp farms were performed at both laboratory and field scale.

2.1,b,iii,1 Stocking and management relationships were investigated in conjunction with the nutrient monitoring programme covered in section (2.1,b,ii). Trophic pathways in shrimp culture ponds were not investigated due to impracticality of stable isotope studies (primarily poor replicability and analytical difficulty). The quantity and form of organic inputs to the shrimp production ponds was investigated as part of the nutrient and solids budget study. Production and feeding efficiency were also monitored, allowing determination of the principal sources and sinks of nutrients in intensive shrimp culture systems.

2.1,b,iii,2, The work carried out on antibiotic uptake in shrimp ran into problems because of a supply of faulty reagents for the Charm system. By the time the source of the problem was resolved, Mr Retamales who was carrying out the work with Dr Brown was no longer available. While the necessity for the data on uptake and residence times is still required, it is encouraging to report that through market and publicity pressure, much of the indiscriminate use of antibiotics in ponds has been curtailed.

2.1,b,iii,3, The over-reliance of shrimp farmers on chemical/mineral pond applications to maintain shrimp pond water quality was highlighted during the investigation of management practices. The efficacy of the most important of these (zeolites), was investigated at both laboratory and field scale.

2.1,c Inputs and Conversion

2.1,c,i, The nutrient budgets derived during this project (section 2.1,b,ii) revealed the over-riding importance of applied formulated feeds under intensive culture conditions. The contribution of natural productivity was concluded to be secondary and emphasised the requirement for optimisation of the formulated diet and feeding management. The regional lack of semi-intensive farms (where natural productivity may assume greater importance) prevented comparative studies being performed in systems at low-intensity.

2.1,c,ii, Feeds are a major proportion of production costs and have a significant effect on the quality of pond water and sediments, and hence shrimp production and farm sustainability. As a major source of nutrients in the intensive shrimp farm system, they also contribute significantly to waste discharge. Minimization of feed wastage and optimization of nutrient usage are emphasised through efficient feeding, reduced stocking and integrated production systems. Manipulation of dietary protein (the most expensive dietary component) is of primary importance in reducing feed cost and wastage. The potential of alternative protein sources including shrimp head meal and chitin was investigated. In addition, protein sparing through substitution of lipid and carbohydrate was studied. Improvement of feeding efficiency and minimization of feed wastage were investigated through the incorporation of feeding attractants in experimental diets. The inclusion of seaweed meal as a shrimp feed component was investigated as a method for improving nutrient utilisation whilst reducing feed cost. The potential integration of *Gracilaria* into shrimp farms to reduce nutrient wastage, and provide an alternative feed component is discussed. The low-technology labour intensive nature of seaweed culture renders its integration into shrimp farms comparatively simple, and offers good employment potential for artisanal labour, especially women.

3. Discussion of the project results.

3.1,a Production, management and impact

3.1,a,i-iii,1, The current status and future of the Thai intensive shrimp industry has been described with respect to its economic and environmental sustainability (Appendices 1 & 2). This report concludes that the unsustainable nature of the Thai intensive shrimp industry has resulted in decreasing pond production, increased crop and farm failure (80,000 ha of shrimp ponds has declined to 40,000 ha in 5 years), and environmental and socio-economic degradation. This is a repetition of previous collapses of the Taiwanese intensive shrimp culture industry. A shrimp farm's ability to produce shrimp at the high densities employed in Thailand (up to 100 shrimp m^{-2}) cannot be sustained in the long term. This is particularly true for the small-scale farms (< 2 ha farm size) which comprise approximately 85 % of the intensive shrimp farms in Thailand. Results from this project indicate that shrimp production is currently declining at a rate of 3 - 8 % per cycle. This declining productivity results from poor growth rates, increased incidence of disease and poor food conversion ratios. The cause of this declining productivity has been studied and is discussed in section 3.1,a,i-iii,2. Further dissemination has occurred through publication of articles on these results in Aquaculture News (Appendices 3 & 4).

3.1,a,i-iii,2, Whilst national production is still increasing (> 170,000 t, worth £ 850 million), this is being achieved by the further intensification of existing shrimp farms. This has resulted in a rise in the numbers of farms failing and the dereliction of large areas of land (300 farms with a total area of 45,000 ha collapsed in one province alone in 1990). Coastal resource degradation has taken the form of salination of freshwater bodies and agricultural land and destruction of mangrove forests. As shrimp ponds become derelict they cannot be reconverted to agriculture due to the salinity of the soil. In the south of Thailand land prices in the coastal zone have increased by 1,000 - 18,000 % with the development of shrimp farms in the region. This has resulted in the extreme marginalization of artisanal coastal farmers and fishermen. The tendency to convert to shrimp farming is accelerated as salination of soil and freshwater results in declining productivity from agriculture. Initially, income from the new shrimp farming operations increases dramatically, but with decreasing production after 2-5 years, the land tends to be abandoned. Farmers then either relocate to other areas or enter other forms of employment, leaving behind large areas of derelict shrimp ponds (Appendix 2).

3.1,a,i-iii,3, The intensive method of shrimp production operating in Thailand originated in Taiwan, and is currently being exported to other countries that are developing their shrimp culture industries. In order to limit the unsustainable development of shrimp farming, certain precautions need to be taken. This project undertook to determine the causes and potential solutions to the current problems within the Thai shrimp industry. The synthesis of this research is presented in Appendices 1 & 2. Economically and environmentally sustainable shrimp culture is feasible, but requires an alternative, longer term approach to shrimp production. The careful control of water and sediment quality within the farm is of paramount importance since these factors determine the productive life of a farm. Loss of productivity, and hence economic viability results from environmental deterioration within the farm and in the surrounding coastal area. The high dependence on formulated feeds by the shrimp industry necessitates good feeding management, optimization of nutrition, and the minimization of waste. The potential for dietary improvement has been studied during this project and this research is described in section 3.1,c. The impact of high densities of shrimp farms within an area is that of self-pollution and contamination of marine and freshwater resources. This results in disease outbreaks and poor productivity within the farms and has unknown consequences on the coastal ecosystem (e.g. fisheries). This emphasises the need for some form of effluent control. The methods to achieve this were studied and are described in section 3.1,b. The relationship between water and sediment quality and farm sustainability was studied during this project and the conclusions are summarised in section 2.

3.1,a,i-iii,4, The development of shrimp farming in an area tends to result in a loss of employment diversity, although the requirements of the industry stimulates supporting infrastructure. This is of critical importance in coastal areas where artisanal agriculture and fishing have been replaced by shrimp farms, feed and chemical retail, shrimp harvesting and processing. These last two categories are major employers of women in coastal zones. The dependence upon one industry in coastal regions emphasises the necessity of stability and sustainability of that industry, and the need for development of alternative forms of employment. Potential methods of integrated sustainable aquaculture (shrimp/seaweed/bivalve culture) as a means of providing alternative employment opportunities, reducing impact and extending the life of shrimp farms are discussed in section 3.1,b,ii,6. Based on the findings of the nutrient budget and water quality research conducted during this project, the integration and uses of seaweeds in shrimp culture systems was studied.

3.1,b Systems and environment

3.1,b,i, Review of stocking practices/post-larval quality

The stocking of good quality post-larvae into ongrowing ponds is essential for the successful production of intensively cultured shrimp. This project followed up work on the previous ODA project in this area through an analysis of intensive nursery-rearing of post-larvae prior to ongrowing (Appendix 5) and in the development of a stress test designed to determine the quality of seedstock (Appendix 6).

3.1,b,i,1, Shrimp are normally stocked into intensive production ponds from hatchery-reared post-larvae, 15 days post-metamorphosis (PL_{15}). The nursery trials were conducted in 25 m^3 outdoor concrete tanks in Thailand in order to assess the role of secondary nursing in the economic production of large, healthy seed. These trials stocked PL_{15} and cultured them for 35 days to PL_{50} at stocking densities of up to 2,000 PL m^{-2}. Various treatments utilising aeration, substrates, habitats, different stocking densities and feeding regimes were tested.

Results showed that there were significant differences between the various treatments. Aeration proved critical for stocking densities from 1,000-2,000 shrimp m^{-2}. Increased stocking density led to concomitant increases in yield (up to 12 g m^{-2} d^{-1}) from the system, but decreased individual growth and survival. Substrates were of no use, but habitats of mesh panels, increasing tank surface area were beneficial at high stocking density. Increases in feeding rate to between 30 and 60 % wet body weight d^{-1} at four feeds day^{-1}, increased production, but decreased water quality. Initial work on nutrition in this nursery system revealed no benefit from high levels of dietary lipid, protein and energy. Subsequent work (currently being prepared for publication) showed that protein-sparing by lipids and carbohydrates, shown to be effective in diets used in the laboratory, could be applied equally well to this system.

Under certain circumstances it was concluded that intensive concrete nursery tanks may present a feasible and economically viable component of intensive shrimp culture. Overall however, such systems were shown to have limitations, particularly in the areas of variable size of juveniles produced and the high risk nature of secondary nursing systems. It was considered that an extension of the primary nursing period within the hatchery, followed by stress testing or some other method of seed quality assessment may offer a more promising method for maintaining high quality seedstock. A paper describing the results from these trials was presented at a conference of the World Aquaculture Society and is included in Appendix 5. Further work on this subject is in preparation for publication.

3.1,b,i,2, As a corollary to the nursery system investigations, a stress test was developed for determining vigour of post-larval shrimp. Techniques are necessary for the objective determination of post-larval quality since it has been suggested that variations in shrimp survival during ongrowing may result from the stocking of low-quality seed. The stress test developed was based on survival of post-larval shrimp subjected to salinity and temperature shock. Results showed that differences between batches of ex-hatchery PL_{15} could be detected. In addition, the larger, more robust PL_{50} produced from the secondary nursing trials discussed above were shown to have greater resistance to environmental shocks. This suggests that they may survive transfer from the nursery to the ongrowing ponds better than the younger post-larvae. However, whether this increased stress-resistance is related to subsequent ongrowing performance, increasing the value of nursed or stress-tested shrimp requires further analysis. A paper on the stress test developed has been published in Aquaculture and Fisheries Management and is included in Appendix 6.

3.1,b,i,3, The generally poor feasibility of secondary nursery rearing techniques, together with the good production obtained by farms using proper environmental management (even when stocking poor quality seed), necessitated a change in emphasis on investigations into post-larval quality. Subsequent work therefore concentrated on the identification of successful pond management techniques in order to enhance shrimp survival, growth and disease resistance during ongrowing. These techniques will be discussed in section 3.1,b,ii.

3.1,b,ii, Nutrient exchange, declining productivity and nutrient cycling

The two year water and sediment quality monitoring programme was completed in August 1993. The results obtained from the programme, together with the additional data derived from liaison with other organisations connected with shrimp farming, enabled quantification of the various components of the intensive shrimp farm system. The data was processed to provide information regarding the nutrient flows through the system and their effects on shrimp and waste production. The potential for modification of the shrimp culture system to improve reliability, nutrient utilization efficiency and reclamation of derelict production ponds was also investigated.

3.1,b,ii,1, Derivation of nutrient budgets

Three types of shrimp production pond were monitored over a period of eighteen months, and the nutrient flow through these systems was determined. This use of three types of pond enabled quantification of the effects of pond age and production intensity on sustainability. Prior to this project, nutrient budgets had not been derived for intensive shrimp production systems. Knowledge of the nutrient flow through aquaculture systems is important with respect to identifying the critical pathways for system optimization and waste reduction. Nutrient budgets were derived for nitrogen and phosphorus, two of the most important nutrients in aquatic systems (Appendix 7).

Largely as a product of protein metabolism, nitrogen in various forms is produced in aquaculture systems. The applied feed represents 50 - 60 % of production costs in intensive shrimp production and protein is the most expensive component of these feeds. The nitrogen budget determined that applied feed represented 95 % of the applied nitrogen to intensive shrimp ponds, yet only 21 % of this was incorporated into the shrimp harvested. Nutrition of shrimp is discussed in more detail in section 3.1,c. The discharge of 79 % of the nitrogen available in a shrimp pond is extremely inefficient and represents a significant resource wastage. The quantity and form of the nitrogen exported from the farm system was quantified in the nitrogen budget. It was found that 35 % of the nitrogen exported from the farms studied was in the water discharged, and that a significant proportion (33 %) of this was during pond harvesting. There exists a potential for nitrogen removal from the water by trapping the nutrient discharged. This would allow secondary aquaculture production, and reduce nutrient discharge. The reduction of nitrogen export from farms by reducing feed wastage is important. This can be achieved by improved feeding management techniques, and better feed formulation. The accumulated sediments trapped 31 % of the applied nitrogen, but their large volume, saline nature and low nutrient concentration limits its potential for useful utilization. The nitrogen concentration of the accumulated sediments is sufficient to cause severe water quality problems if it is not removed between crops.

Phosphorus is a major plant nutrient and is responsible for algal productivity in marine areas. The discharge of phosphorus into coastal environments can have serious implications for coastal fisheries and aquaculture. The stimulation of toxic algal blooms can cause production loss from shrimp farms and other coastal aquaculture (especially shellfish) and heavy oxygen demands occurring when blooms crash can cause fish kills in coastal areas. In intensive shrimp farms the majority of the phosphorus applied to the ponds is derived from the feed (51 %), with a significant contribution from the pond soil (26 %). The accumulated sediments are the principle sink for phosphorus (93 %), thus correct disposal of the sediments is important.

The conclusion of the nutrient budget studies was that, provided ponds were well cleaned between cycles, pond age did not markedly affect the nutrient levels. This is of importance to the maintenance of farm sustainability. The effect of stocking density was reflected as increased nutrient flow due to the higher feed application, but the relative proportions of the various sources and sinks was not affected. The principal factors affecting pond production were the management of water and sediment quality during production. These are discussed in more detail in sections 3.1,b,ii,4-5. What is clear is that as production intensity increases so does nutrient flow, increasing the likelihood of deteriorating water and sediment quality, thereby compromising farm sustainability.

3.1,b,ii,2, Solids budget and settlement characteristics of effluents

As part of the water and sediment quality monitoring programme, the role of solids in intensive shrimp farms was studied. The accumulation of sediments can be critical to farm sustainability, and these sediments play an important role in determining pond water quality. The derivation of solids budgets for the three types of shrimp farm studied has allowed the relative importance of the different sources of solids to be assessed. The organic content of these solids has also been incorporated into a budget and the relative contributions of the feed, inlet water and pond soils have been quantified (Appendix 8).

The erosion of pond soil due to the strong aeration and water circulation was shown to be the principal contributor of solids in the farms studied (88 - 93 %), the weight of accumulated sediment being considerable (185 - 199 t ha^{-1} $crop^{-1}$). The contribution of influent water sediment loadings was relatively small (2 -3 %). This is a significant discovery, since it is assumed that sediment accumulation generally results from feed and influent water. If erosion of pond soil could be minimized through the use of lining compounds, the effect of sediment accumulation would be reduced. This would have a profound effect on pond water quality and the sustainability of shrimp ponds since 58 - 70 % of the organic matter introduced to the ponds remained in the accumulated sediment. This sediment requires removal and disposal, and represents a major export of nutrients from the system. The use of lining compounds also prevents the organic content of the eroded soil affecting water quality. The organic content of the soil eroded from the pond bottom and walls contributed approximately 40 - 60 % of the organic matter applied to the ponds. Minimizing this input is seen as an extremely effective way of improving nutrient utilization in shrimp ponds.

The settlement of suspended solids was also studied in order to characterize the nature of solids in shrimp farm effluents. The solids component of shrimp effluents can be divided into settleable and non-settleable fractions. Settling ponds will remove some of the solids from effluents, but a large proportion (56 - 78 %) will not be removed, even after three hours, and will impact on the environment. This fraction is also nutrient rich (30 % organic matter) and could provide nutrition for bivalves or filter feeding fish. The production of suspended solids by intensive shrimp farms is one of their greatest impacts on both themselves and on local water bodies.

3.1,b,ii,3, Dissemination of information at the AAHRI workshop on shrimp health management

The conclusions of the research performed during this project and its implications for shrimp farm sustainability was presented at the Aquatic Animal Health Research Institute (AAHRI) Shrimp Health Management Workshop (Bangkok, 11 - 18 January, 1994)(Appendix 9). The presentation included management strategies for maintenance of pond water and sediment quality, minimization of waste output and the use of integrated culture systems. The critical aspects of shrimp farm sustainability were discussed, particularly with respect to the regional implications of uncontrolled shrimp farm development. Participants at this workshop were representatives from the ASEAN region, and it is hoped that further presentations of this type will take place in the future.

3.1,b,ii,4, Pond soil and sediments - effects of age and stocking density

Analysis of pond soils from the three types of farm revealed that pond age or stocking density had little effect upon the composition of pond soil (Appendix 10). This was concluded to be due to the constant removal of pond soil by the scouring action of the aeration equipment. The sediments that accumulated as a result of soil erosion and feed applications became progressively more organic through the culture cycle. In ponds stocked at the highest density, the greater rate of feed application elevated the sediment organic content more than the less highly stocked ponds. Sediment quality is also seen to deteriorate through the culture cycle, leading to solid wastes occupying ever greater areas of the pond bottom. These areas then provide an inhospitable and anoxic environment for the shrimp, effectively increasing shrimp densities and hence stress further. Due to the high quantities of waste food and shrimp waste, the percentage of organic material in the sediments thus builds up through the cycle, particularly in ponds which are more highly stocked. The original organic content of the pond soil appeared to have a significant effect upon the organic composition of the accumulated sediment. It was concluded that shrimp ponds built on highly organic soils would suffer from water quality problems more rapidly than those constructed on less organic soils. The large contribution of the pond soil to sediment accumulation masked the effects of pond age and stocking density, such that definitive differences between management methods were not obtained. The practice of cleaning the production ponds between cycles appears to be effective in preventing the build up of organic matter in the sediment remaining in the ponds. Ineffective sediment removal or highly organic pond soil were concluded to be the greatest threat to pond sustainability. The potential for the use of pond liners to cover the areas eroded by water movement was concluded to be an effective method for reducing sediment accumulation, whilst enabling thorough pond cleaning between crops. Disposal of the sediment removed from shrimp ponds between crops is an increasing problem since its saline nature and relatively low nutrient content renders it a poor fertilizer. The sediment has a silty composition which also causes it to be of little use for construction purposes.

3.1,b,ii,5, The effect of water quality on shrimp farm production

One of the objectives of the water quality monitoring programme was to relate management practices to declining productivity. The relationship between the management of the pond environment, shrimp health and production is undeniable, yet has never been quantified. This is primarily due to great variability in conditions between replicate ponds and the time and effort required to conduct such a study. The water quality monitoring programme was able to demonstrate the effect of stocking density upon pond water quality, and also identify the probable causes of declining pond productivity. Quantification of discharges from the different pond types during routine water exchange and shrimp harvest was performed. This information has hitherto been lacking and this study will enable the impact of shrimp farming developments to be quantified relative to other coastal discharges (i.e. urban, industrial and agricultural effluents). This information has been written up for publication and is included in Appendix 11.

The quality of influent water supplies did not deteriorate during the lifetime of the project. Seasonal differences in influent water quality were detected and were concluded to result from the stirring up of sediments in the sea during monsoon storms. This increased the coastal suspended solids loadings, but nutrient inputs were minimal relative to the other applications to the production ponds. These results are in contrast to those seen in other areas of Thailand and elsewhere, where the reliance on canal-fed water supplies to a number of ponds (which use the canals for both water supply and discharge), have led to rapidly deteriorating water quality. This emphasises the benefit of the separation of inlet and outlet water supplies and the advantages in terms of sustainability obtained by direct abstraction of inlet water from the sea. The use of settling ponds reduced high suspended solids loadings, but had little effect on nutrient levels.

The water quality conditions in the ponds themselves were seen to deteriorate rapidly over the four month culture cycle. This effect was more pronounced when the ponds were stocked at high density, but pond age seems to have little effect on pond water quality. Similarly, the reduction seen in pond productivity over the monitoring period (3 - 8 % $crop^{-1}$), and the loss of the entire crop in some ponds cannot be related to pond age, but rather to poor pond management. This takes the form of a build up in nutrient levels within the ponds to toxic levels and the inadequate control of phytoplankton leading to bloom crashes. Additionally, the wide diurnal fluctuations in dissolved oxygen and pH as a result of heavy phytoplankton blooms and high sediment oxygen demand, results in chronic stress to the shrimp. This is thought to reduce feeding activity and hence growth and also increases susceptibility to disease. All of these conditions contribute to lower than expected production levels.

Although the ponds stocked at high density gave significantly higher production throughout the monitoring period, both the water and sediment quality of these ponds was invariably inferior to that measured in the lower density ponds. The management of the water quality was also more difficult due to the excessive nutrient load applied to the pond environment. In particular, stable algal blooms could not be maintained, resulting in frequent crashes. The collapse of a farm, as seen in the north Gulf of Thailand was not observed during this monitoring period, but the highly variable production due to the poor management of these farms suggests that their current production levels are not sustainable. The high stocking densities employed on most small-scale Thai shrimp farms require effective management if production problems are to be avoided. This ability is lacking on most farms, although economically viable shrimp culture can still occur due to the high profitability of shrimp farming. The sustainability of such practices however, is low due to the gradual decline in productivity and increasing risk of crop loss as the farm ages.

The principal method for maintaining the biological viability of a farm is concluded to be the reduction of stocking density. This reduces feed inputs and waste production, optimizing natural decomposition processes. A stocking density of 25-30 shrimp m^{-2} has been suggested to slow pond deterioration and reduce disease incidence, yet still achieve optimum profitability over the longer term. The stocking densities used in intensive shrimp culture in Thailand (up to 100 shrimp m^{-2}) are thus demonstrably unsustainable.

3.1,b,ii,6, The integration and potential role of seaweeds in shrimp culture

The high nutrient loadings present in intensive shrimp culture systems present serious problems to the farmer. The simplest solution to this problem is reduction of stocking density, but this is not always an option for the farmer. The high density of farms in some areas, and the high nutrient loadings produced by other effluents can cause problems irrespective of the stocking density employed. The potential for integrated culture systems has been investigated during this project, specifically the integration of the seaweed *Gracilaria spp.* into shrimp production.

A review of the potential for *Gracilaria spp.* or other macroalgal culture in conjunction with other aquacultured species was submitted to the Conference on Marine Biotechnology in the Asia Pacific Region (Bangkok, 16 - 20 November, 1993)(Appendix 12). This review concluded that the removal of nutrients from aquaculture effluents could enhance the quality of effluent water and improve nutrient utilization efficiency. The high market price for agar and the employment opportunities afforded by seaweed culture suggests considerable potential for its integration into shrimp culture.

A study of the nutrient removal capacity of *Gracilaria spp.* and its growth in shrimp farms was performed (Appendix 13). This research involved microcosm studies of seaweed performance under ideal conditions and also those found in shrimp farms. The trials performed at the Tinsulanonda Songkhla Fisheries College revealed rapid uptake of ammonia from brackishwater, and the removal of other nitrogenous compounds. This uptake was equivalent to growth rates of up to 4.7 % wet wt. day^{-1}, comparable to the results of previous research. Trials performed at the shrimp farm revealed good growth rates (3.4 % wet wt day^{-1}) when *Gracilaria* was cultured in the influent reservoir of the shrimp farm. This suggests that the temperature and salinity conditions are suitable for the culture of this species. Culture of *Gracilaria* in the effluent water from the farm caused rapid mortality of the seaweed due to fouling with sediment and low oxygen concentrations. Pre-settlement and aeration causing water movement allowed the survival of the seaweed but growth was poor. This study concluded that there is potential for integration of seaweeds into shrimp culture systems, but that aeration should be provided and substantial settlement of solids is required. The culture of *Gracilaria* within shrimp production ponds was evaluated for its role in ammonia removal and control of phytoplankton. The presence of high aeration and water movement should prevent sedimentation and fouling. The integration of seaweed as a tertiary treatment after settlement and solids removal by bivalves in recirculated systems shows good promise. Seaweed cultivation offers good employment potential for women and coastal inhabitants not involved in shrimp culture. The labour intensive nature of seaweed culture combined with its ease of production make it an ideal low capital input enterprise. It can therefore exist alongside shrimp production, with mutual benefits accruing to both culture systems. There exists a considerable area of land in Thailand (> 45,000 ha) that is now unfit for shrimp production that could be converted to seaweed culture allowing its reclamation for culture. The integration of low intensity shrimp farming could improve the economic viability of such a venture, and its low impact would certainly be environmentally sustainable.

The results of some of this work were presented by Dr. Funge-Smith as a poster at the Conference on

Marine Biotechnology in the Asia Pacific Region (Bangkok, 16 - 20 November, 1993).

3.1,b,iii, Fate and impacts of pond treatments

The large variety of pond treatments utilised in intensive shrimp culture was the subject of research during this project. The over-reliance of shrimp farmers on chemical/mineral applications to maintain pond water quality was highlighted during the investigation of management practices. Many of the treatments in common use in Thailand and elsewhere are extremely costly, are of questionable efficacy and have currently unknown effects on the environment once discharged from culture ponds. A review of pond application use is included in Appendix 2, but special emphasis was placed on specific treatments causing concern for research during this project. Research into antibiotics, in common use in intensive shrimp farms and prompting concern over their possible abuse, was planned for this project. Zeolites, commonly used for the enhancement of pond water quality in intensive shrimp culture, were investigated due to doubts over their efficacy and cost-effectiveness in this role (Appendices 14 & 15).

3.1,b,iii,1, The antibiotic studies ran into a number of problems, the most serious of which was that a batch of reagents supplied by Penicillin Assays Inc. were faulty and a considerable input of time including one whole trial was lost. Replacement reagents were provided but unfortunately Mr Retamales was then unable to continue the work due to the extreme ill-health of his wife.

Recently (1993) bans on the import of shrimp containing antibiotic residues into Japan and the USA have been imposed. These countries are the principal markets for shrimp from Thailand and elsewhere and so this has had a significant impact on the use of antibiotics in Thai shrimp culture. Due to lack of knowledge on residence times of antibiotics within shrimp (and the pond environment and discharged wastes), antibiotic use in Thai shrimp farms has declined dramatically. Further research is necessary however, to determine whether antibiotics can have a positive role in intensive shrimp production which outweighs their expense and possible damage to the environment or human health.

3.1,b,iii,2, An investigation was made into current management practices for improving water quality during this project. The main results have been discussed in section 3.1,b,ii, but the use of zeolites for enhancement of shrimp pond water quality was highlighted as being worthy of further investigation. Zeolites are most commonly used as ion exchangers in an effort to reduce levels of toxic nutrients, remove suspended solids and improve sediment quality and water colour. In the Ranod/Hua Sai areas of southern Thailand, where the majority of this project was conducted, roughly 43 % of the farmers report using zeolites. At the dose rates and frequency used this equates to an annual expenditure of £ 0.9 million in these areas alone. There are, however, doubts as to the effectiveness of zeolites in alleviating these problems. This research was therefore conducted to test the effect of zeolites on water quality under a range of conditions in both laboratory and field situations.

A series of seven small scale laboratory-based tank trials and one full-scale pond trial were conducted at the Tinsulanonda Songkhla Fisheries College. These trials investigated the effects of six types of locally available zeolites and three other alumino-silicate clays at levels from one to 26 times the recommended dose rates in water at salinities from 0-30 ‰ for periods of up to 19 days. Results from the laboratory trials showed that none of the zeolites or other alumino-silicate clays were able to either act as ion exchangers, absorbing dissolved organic nutrients from the water, or prevent their emission from nutrient-rich shrimp pond mud in water at any salinity from fresh too full-strength seawater. A field trial in shrimp production ponds also failed to reveal significant benefit to using zeolites in terms of reducing levels of toxic dissolved or particulate organic nutrients, or suspended solids or in enhancing algal biomass. This study could not establish any useful, cost-effective role for zeolites in shrimp pond culture. The belief of shrimp farmers that zeolites improve poor water quality was thus exposed as completely erroneous. Use of these expensive applications should therefore be replaced by other management techniques which are able to improve the water quality of intensive shrimp ponds. These techniques have been discussed in section 3.1,b,ii. The results of the zeolite work have been submitted for publication in Aquaculture and Fisheries Management (Appendix 14). The information has also been presented in Thai and English at two conferences in Thailand and will be published in the AAHRI newsletter in June 1993 (Appendix 15).

3.1,c Inputs and conversion trials

3.1,c,i, The contribution of pond biota to shrimp nutrition was not studied due to difficulties with the planned stable isotope studies. This was largely due to the difficulty of analysing samples and poor replicability of the results. The nutrient budgets discussed in section 3.1,b however, revealed the overriding importance of applied formulated feeds under intensive culture conditions. Nutrition of shrimp at stocking densities of only 17-30 shrimp m^{-2} is partially derived from the pond biota, but at the densities investigated during this study (100 shrimp m^{-2}), the importance of added feeds increases. Feed represents 50-60 % of the operational costs and provided 92 % of the nitrogen and 51 % of the phosphorus entering the intensive culture ponds. In addition, wastage of applied feeds (only 14 % is incorporated into shrimp biomass) makes a significant contribution to the wastes emitted from such ponds. Because of the importance of applied feeds in all of these areas, work in this section concentrated on defining the nutritional requirements of the shrimp; optimizing the nutritional profile of the diet; and reducing the cost of the diet through studying the potential for protein sparing by lipids and carbohydrates and investigation of alternative feedstuffs for inclusion into the diets.

3.1,c,ii,1, A nutritional review for penaeid shrimp has been produced and is currently in press. Major conclusions from this review were that although much work has been conducted on shrimp nutrition over the last 20 years, there is still much to be learnt. Specifically, the role of nutrition in maturation requires further research. Sparing of protein by manipulation of dietary energy sources is necessary for the production of low-cost diets. The relationship between nutritional trials conducted in the laboratory and optimised feeding of applied feeds and natural productivity in the pond is little understood. Finally, the relationship between nutrition and stress/disease in shrimp requires further investigation.

3.1,c,ii,2, Optimization of the nutritional profile of applied feeds with a view to supplying least-cost diets has been studied extensively both in the laboratory and the field in Thailand. One paper has been published (Appendix 16), two more submitted (Appendices 17 & 18) and a further one is in preparation for later publication. Protein is the most expensive component of formulated diets and fish meal (the most common protein source) often has to be imported at great expense from abroad. Papers have been produced investigating the protein-sparing abilities of lipids and carbohydrates in diets for shrimp. Major conclusions have shown that in the laboratory, protein levels can be reduced from the currently common level of 44 % to 38 % (or less) if dietary energy levels are maintained (19-20 Kj g^{-1}) through supplementation of lipids and carbohydrates. Lipid levels, including 3 % lecithin, of up to 12 %, in combination with up to 30 % carbohydrate result in low-cost, nutritionally optimum diets. Work conducted on the same diets in both the laboratory and in outdoor tanks in Thailand has shown that results are similar for the two systems. What still requires investigation however, is the extent to which natural productivity can be utilised to replace the complete dependence on formulated diets under intensive culture situations. This area was not investigated during the project, but is important for further minimization of feeding costs.

3.1,c,ii,3, Nutritional studies have also involved the derivation of an energy budget model for shrimp. This work is complementary to the nutrient budget work in shrimp ponds detailed in section 3.1,b,ii.

The field monitoring in Thailand allows overall inputs and outputs to be quantified but there is still a gap in knowledge as to how the shrimp process feed and their utilisation efficiency. A series of digestibility trials were carried out studying the effects of fibre, carbohydrate and protein levels on the digestibility of shrimp diets. This work is currently being written up for publication.

3.1,c,ii,4, Work investigating the role of a range of feeding attractants in stimulating consumption of diets by shrimp has also been conducted and a paper published in Aquaculture (Appendix 19) and presented at a symposium on coastal zone management in Indonesia (Appendix 20). Conclusions from these trials showed that some of the attractants tested (specifically, taurine, an amino acid mixture and a yeast extract) were responsible for positive behavioural responses and improved growth and feed conversion efficiency of the shrimp. The results justify further studies in this area. The effect of adding feeding attractants to commercial type diets (i.e. fish/shrimp meal based diets) should be investigated. It is possible that high levels of substances such as taurine already exist in more practical diet formulations. These might over-ride any additional benefit in adding further attractants. Prior to carrying out further practical work, a cost/benefit analysis should be made to determine whether the use of feeding attractants could be economically justified.

3.1,c,ii,5, Trials have also been conducted in the laboratory investigating some potential alternative feedstuffs for inclusion into shrimp diets. These trials have studied ingredients including chitin, shrimp head waste and *Gracilaria* seaweed meals.

The chitin trial revealed that chitin, incorporated into commercial diets with the use of shrimp head meal is not directly utilized by the shrimp. Under pond conditions however, it may be indirectly utilized via gut or sediment bacteria. In addition, proteins, lipids and minerals associated with native chitin may be useful to the shrimp. This work has been published in Aquaculture (Appendix 21). Further studies to assess the role of gut bacteria in shrimp digestion and the utilization of unpurified chitin in pond-grown animals may yield valuable information.

Chitin as an essential component of the shrimp exoskeleton is found in commercial shrimp feeds as a consequence of the inclusion of shrimp head meal. This material is obtained as ground sun or oven-dried whole shrimp heads which are a by-product of the shrimp processing industry. A study was conducted using a novel but simple method developed by NRI, of separating shrimp-head waste into a chitin rich fraction and a protein rich fraction, for incorporation into diets which could increase the economic incentive for recycling this waste material. A cost benefit analysis has been carried out by the Natural Resources Institute (NRI) to analyze whether recycling shrimp waste would be economic. This analysis indicated that the process would break-even. Benefits would be higher if the protein-enriched material had a growth promoting effect in shrimp and if the chitin fraction was sold separately. In the analysis the chitin fraction was not given an economic value.

The nutritional study carried out evaluated meals derived from shrimp head waste as dietary components for shrimp. A supply of raw, frozen, shrimp-head waste was imported from Thailand. This material was processed at NRI into six fractions :- solar dried, oven dried and four fractions in which the majority of chitin is removed by varying processes. Diets were prepared from this material at Stirling and evaluated against a fish meal based diet. The results from the trials showed that the addition of shrimp head meals had a positive effect on shrimp production and that the processing method significantly affected the degree of benefit. This confirms the promise that these materials and production methods hold for replacing expensive fish meal in shrimp diets. This publication is in press in Aquaculture (Appendix 22).

As a corollary to work investigating the potential of seaweed in integrated shrimp culture to remove nutrients from shrimp farm effluents in Thailand, the potential use of *Gracilaria* meal as a feed ingredient has been investigated in nutritional trials in Stirling. Results indicated that inclusion of seaweed meal has no positive effects in enhancing the growth or survival rates of shrimp. However, up to 15 % of soyabean meal and wheat flour components of the basal diet could be replaced by *Gracilaria* meal without any significant decrease in performance. These results suggest that, with the integration of seaweed and shrimp culture, the virtually cost-free production of seaweed meal may have potential for reducing the feed costs and hence increasing the profitability of shrimp farming. It may also have potential to provide an additional source of revenue and employment for low-income coastal inhabitants. This work has been written up and submitted for publication in Aquaculture and Fisheries Management (Appendix 23).

4. Implications of the results for Development

The sustainability of shrimp farm systems has two components, economic and environmental. Short term economic sustainability is the current approach to intensive shrimp farm development in most countries, resulting in extremely poor environmental sustainability. Environmental degradation as a result of uncontrolled shrimp farm development has resulted in profound socio-economic changes in coastal communities, raising questions as to the benefit of such development. The development implications of this project can be split into four categories, and these are dealt with below:

4.1, Causes of unsustainability in the shrimp culture system

An analysis of the development of the intensive shrimp farming industry in southeast Asia within this project has highlighted the historical unsustainability of the industry. The current status of the global shrimp industry is one of increasing competition and intensification. The current slash and burn type development still allows profitable shrimp culture but causes increased production losses and extreme coastal resource degradation. The increased risk and reduced economic returns as a result of this style of farming requires a new longer term approach to shrimp culture. This project was set up to gain a better understanding of the processes acting within shrimp ponds and their relationship to unsustainable farming practices. Many hypotheses have been proposed as to the underlying cause of farm unsustainability and declining productivity, but no definitive answers have previously been determined. Identification of some of these factors during this project will facilitate the strategic planning and development of a more environmentally and economically sustainable industry. This will necessitate coastal planners and investors taking a more long term approach to the role of shrimp culture in coastal development.

4.2, Inputs and outputs of shrimp farm system - strategic management implications

The water and sediment monitoring programme undertaken during this project has helped to quantify and qualify the nutrient flows through the intensive shrimp system. This has allowed definition of the critical management and economic aspects of sustainable shrimp culture. Specifically: the over-riding importance of reducing stocking density, improved feeding management and feed composition and the management and control of pond water and sediment quality. Methods for the minimization of waste discharge through treatment and integrated culture systems have been proposed in this project. Salination of freshwater and agricultural resources, shrimp farm dereliction and degradation of the coastal environment have resulted from unsustainable shrimp culture. This has caused loss of employment diversity and socio-economic hardship to coastal communities. The potential for reclamation of ex-shrimp farming land using sustainable aquaculture techniques is discussed. Strategies for the culture of alternative marine species, or low intensity integrated shrimp farming in these areas are suggested.

4.3, Impacts of shrimp farming on coastal resources

Lack of legislation and control regarding waste emission from shrimp farming has historically been due to lack of quantitative data. The investigation of the outputs from typical intensive shrimp farms has allowed the impact of wastes from shrimp farming to be quantified for the first time. It is anticipated that these results will enable effective identification of key parameters for monitoring the effluent loadings produced by shrimp farms and allow sensible legislation. In those countries that have no restrictions on farm construction, rapid farm failure due to overintensification is expected and results in exploitation of virgin areas for short term profit. The controlled development of shrimp farming is of major importance for those developing countries currently expanding their shrimp culture industries. Without control, they can expect the same kind of environmental and resource degradation as that already experienced by Taiwan and Thailand. The challenge to the countries developing shrimp farming is to implement sustainable shrimp culture whilst maintaining competitiveness.

4.4, Remediation

Current management practices employed in intensive shrimp culture place heavy reliance on chemical/mineral applications in order to maintain suitable water quality. These applications represent a significant cost in their own right, and their questionable effectiveness may cause reduced production and hence lowered income. Analysis of the effectiveness of these applications during this project has shown their inability to fulfil any of the functions attributed them. This emphasises the importance of effective water, sediment, feed and waste management techniques. The training of farmers in sustainable management techniques is seen to be of prime importance for the long-term viability of the industry.

Traditionally, little emphasis has been placed on the limitation of waste discharge from farms due to cost and lack of perceived impact. The overintensification of shrimp farm developments in Taiwan and Thailand has indicated the increasing necessity of waste treatment. In order to maintain the long-term profitability of shrimp culture, the minimization of impact within and outwith shrimp farms is critical. The development of low cost, low waste and nutritionally optimal diets and feeding management strategies is important for maintaining a healthy pond environment and minimising waste production. The limited and often ineffective use of physical settlement of farm wastes requires the adoption of an alternative approach to the minimisation of impacts of shrimp farms on the coastal environment. Integration of biological treatment methods (i.e. seaweed and bivalve) into shrimp culture systems shows good potential for reducing these impacts. The additional benefit of low impact/integrated culture systems is the employment potential offered by its low technology requirements. This is of considerable importance to coastal communities where traditional methods of coastal resource utilization have been compromised by shrimp farm development. The work currently in progress on these systems should be encouraged in order to demonstrate their economic viability and the potential for profitable, sustainable aquaculture.

5 Priority tasks for follow-up

5.1 Further dissemination of information

The findings of this project have highlighted the principal causes of shrimp farm unsustainability and provided a range of potential solutions. Dissemination of these findings as widely as possible is essential, particularly in the areas of coastal development and planning, and the funding of shrimp farm development projects. A priority for further research is the study of how shrimp culture can be integrated sustainably into coastal development. It is generally assumed that the income from intensive shrimp farming more than offsets the environmental degradation and loss of resource diversity. It is now becoming apparent that this is not the case and the role of shrimp farming needs to be re-evaluated in the context of the sustainable use of land and water resources. The dissemination of this work to key people in the shrimp industry is of strategic importance to the development of a more sustainable approach to shrimp culture.

During the course of this project, results have been presented at seminars, conferences and workshops within Thailand (see below). Additionally, presentations at the AAHRI Shrimp Health Management workshop in Bangkok ensured that the project findings reached an audience within the ASEAN countries.

There will be 15 publications produced from this project, published in peer reviewed journals. Another four articles have so far been written for more general publications. These are more widely available to the relevant audiences and it would be useful to publish an overview article in a less technical journal such as World Aquaculture. The Institute of Aquaculture has an advantage in being able to disseminate findings via its international student intake. This is achieved by specialist seminars, student projects, as part of the normal post-graduate teaching, and through publication of articles in the newspaper produced by the Institute, Aquaculture News.

While the possible integration of seaweed and bivalves into shrimp culture are discussed in papers produced during this project, more detailed clarification of this work is needed. The potential for pond reclamation, nutrient removal and resource utilization efficiency offered by these methods is still poorly understood. Further research will establish the potential of these systems and allow their technical and economic feasibility to be assessed. It is necessary to validate to what extent the conclusions of this project could be applied to different management systems. The production and economic modelling of the effects of different managements strategies on different shrimp culture systems will allow the feasibility of some of the proposals of this project to be assessed. Validation of this work through field surveys will allow such models to be based upon realistic data.

Further liaison with organizations associated with the shrimp industry will allow the wider dissemination of the results and publications generated by this project. It is intended that upon publication, papers will be sent to key shrimp research institutions around the world. This is of importance regarding dissemination of information to the USA and central and south America where this work will have increasing relevance as further intensification of shrimp culture occurs in this region.

5.2 Conferences attended

Mr Briggs attended the 22nd World Aquaculture Society Conference in Puerto Rico in July, 1991. Here, the results from the nursery tank trial and stress testing studies were presented to an audience of people from around the world involved in the aquaculture industry.

Mr Briggs attended the Tenth Year Conference at the Tinsulanonda Songkhla Fisheries College, Songkhla, Thailand in June 1993 and presented the results of his work on pond water quality entitled "Water quality in sustainable shrimp farming",

This work was also presented at the DOVE Conference in Krabi, Thailand in July, 1993. The results of his work on zeolites were also presented in a paper entitled "The effectiveness of zeolites and other alumino-silicate clays in reducing the level of organic nutrients in water at various salinities". This conference was attended by representatives of the Thai Department of Fisheries, local shrimp farmers and shrimp industrialists and staff and students of the College.

Dr Funge-Smith also attended the DOVE conference and presented a paper entitled "The nature of sediments in intensive shrimp ponds".

Dr Funge-Smith attended the Conference of Marine Biotechnology in the Asian Pacific region, 16-20 November, Bangkok and submitted a poster presentation entitled "Nutrient uptake and Growth of *Gracilaria* spp. in Intensive Shrimp Farm Effluent". This conference included representatives from several branches of marine biotechnology but was largely concerned with the high science approach to biotechnology. The shrimp farming special session concentrated on gene probe diagnostics and disease free stock production for avoiding shrimp disease - the simple and effective approach of environmental control was noticeably absent. A joint abstract/summary paper by Mr Briggs and Dr Funge-Smith entitled "Macroalgae in Aquaculture: An overview and their possible roles in shrimp culture" was also submitted to this conference and is published in the proceedings.

Dr Funge-Smith attended the Asian Fisheries Society Symposium "Aquatic Animal Health and the Environment" 25-29th October, Phuket, Thailand. The two keynote speeches both emphasised the importance of maintaining environmental quality in avoiding disease.

Dr Funge-Smith attended the VSO/CUSO conference on coastal resources in NIFI, Bangkok, Thailand from 15-20 July, 1993 where he presented a paper entitled "Suitable strategies for sustainable shrimp farming". This participants at this conference were all working at extension level, within the field of coastal and freshwater aquaculture.

Mr Briggs attended the AAHRI Shrimp Health Management workshop in Bangkok from January 11th -19th 1994 and presented a paper "Nutrient modelling in sustainable shrimp farming" This workshop was attended by delegates, working in the field of shrimp culture, from all over the ASEAN region.

5.3 Complete list of publications

1. Briggs, M.R.P. 1992. A stress test for determining vigour of post-larval *Penaeus monodon* Fabricius. *Aquaculture and Fisheries Management* **23,** 511-515.

2. Briggs, M.R.P. 1992. Four years of ODA-supported collaboration between the Tinsulanonda Songkhla Fisheries College, Thailand and the Institute of Aquaculture. Article in *Aquaculture News,* **14,** July, 1992, 1 p.

3. Briggs, M.R.P. 1993. Water quality and treatment in sustainable shrimp farming. Paper presented at the *Tenth Year Anniversary Conference of the Tinsulanonda Songkhla Fisheries College, Songkhla, Thailand.* 2nd-4th June, 1993, 35 pp.

4. Briggs, M.R.P. 1993. Water quality in sustainable shrimp farming. Paper presented at the *Third Academic and Research Conference for Southern Thailand Technical Colleges. Krabi, Thailand.* 23-25 July, 1993, 20 pp.

5. Briggs, M.R.P. 1993. The effectiveness of zeolites and other aluminosilicate clays in reducing the level of organic nutrients in water of various salinities. Paper presented at the *Third Academic and Research Conference for Southern Thailand Technical Colleges. Krabi, Thailand.* 23-25 July, 1993, 15 pp.

6. Briggs, M.R.P. 1993. Status, problems and solutions for a sustainable shrimp culture industry with special reference to Thailand. *Unpublished report to the ODA*. 41 pp.

7. Briggs, M.R.P. 1994. Nutrient modelling in sustainable shrimp farming. Lecture presented at the *AAHRI/ODA Shrimp Health Management Workshop,* Aquatic animal Health Research Institute, Kasetsart University Campus, Bangkok, 11-18 January, 1994.

8. Briggs, M.R.P. 1994. The effectiveness of zeolites and other aluminosilicate clays in reducing the level of organic nutrients in water of various salinities. *AAHRI Newsletter,* June, 1994, 1 p.

9. Briggs, M.R.P. and Brown, J.H. 1991. Intensive rearing of post-larval *Penaeus monodon* Fabricius in concrete nursery tanks. Paper presented at the *22nd World Aquaculture Society Conference,* San Juan, Puerto Rico. June, 1991, 19 pp.

10. Briggs, M.R.P. and Brown, J.H. (submitted to *Aquaculture and Fisheries Management*). Protein-sparing effects of dietary lipid and carbohydrate on performance, carcass composition and histology in post-larval *Penaeus monodon* Fabricius fed semi-purified diets in the laboratory.

11. Briggs, M.R.P. and Funge-Smith, S.J. 1993. Macroalgae in aquaculture: an overview and their possible roles in shrimp culture. In. *Proceedings of the Conference on Marine Biotechnology in the Asia Pacific Region. Bangkok, Thailand.* 16-20 November 1993, 5 pp.

12. Briggs, M.R.P. and Funge-Smith, S.J. 1994. Shrimp farm environmental quality - its relationship to sustainability. *Aquaculture News* **17,** 1994, 1 p.

13. Briggs, M.R.P. and Funge-Smith, S.J. (submitted to *Aquaculture and Fisheries Management*). The potential of *Gracilaria spp.* meal for supplementation of diets for juvenile *Penaeus monodon* Fabricius.

14. Briggs, M.R.P. and Funge-Smith, S.J. (submitted to *Aquaculture and Fisheries Management*). The effects of zeolites and other alumino-silicate clays on water quality at various salinities.

15. Briggs, M.R.P. and Funge-Smith, S.J. (submitted to *Aquaculture International*). Unsustainable shrimp culture - causes and potential solutions from experience in Thailand.

16. Briggs, M.R.P. and Funge-Smith, S.J. (in press). A nutrient budget of some intensive marine shrimp ponds in Thailand. *Aquaculture and Fisheries Management.*

17. Briggs, M.R.P., Brown, J.H. and Fox, C.J. 1993. The effect of dietary lipid and lecithin levels on the growth, survival, feeding efficiency, production and carcass composition of post-larval *Penaeus monodon* Fabricius. *Aquaculture and Fisheries Management* **25,** 1-16.

18. Briggs, M.R.P., Fox, C.J. and Brown, J.H. 1994. The effects of dietary carbohydrate and lipid levels and their ratio on performance, carcass composition, midgut gland amylase activity, diet digestibility and histology in post-larval *Penaeus monodon* Fabricius. *Aquaculture and Fisheries Management* (submitted).

19. Fox, C. 1993. The effect of dietary chitin on the growth, survival and chitinase levels in the digestive gland of juvenile *Penaeus monodon* (Fab.). *Aquaculture* **109,** 39-49.

20. Fox, C., Brown, J.H. and Briggs, M.R.P. 1994. The nutrition of shrimp and prawns - A review of recent research. In: *Recent Advances in Aquaculture* **V.** Blackwells (in press, 1994)

21. Fox, C.J, Blow, P., Brown J.H. and Watson I. 1994. Processing of shrimp head waste for incorporation into shrimp feeds: the effect of various processing methods on the physical and biochemical properties of meals prepared from shrimp head waste and the effect of incorporating shrimp head meals into a fish-meal based on the growth, survival and carcass composition of juvenile *Penaeus monodon* Fab. *Aquaculture* (in press, 1994).

22. Funge-Smith, S.J. 1993. The nature of sediments in intensive shrimp ponds. Paper presented at the *Third Academic and Research Conference for Southern Thailand Technical Colleges. Krabi, Thailand* 23-25 July, 1993, 3 pp.

23. Funge-Smith, S.J. 1993. Suitable strategies for sustainable shrimp farming. Paper presented at the *VSO/CUSO conference on coastal resources. Bangkok, Thailand.* 15-20 July, 1993, 5 pp.

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