Coastal Shrimp Aquaculture in Thailand: Key Issues for Research

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Preface

'Key Researchable Issues in Sustainable Coastal Shrimp Aquaculture in Thailand' was a project, which originated in 1994 through a proposal to the Australian Centre for International Agricultural Research (ACIAR) by Professor Ian White and Dr Banchong Tiensongrusmee. Because of their enthusiasm and energy, the proposal became a reality. Substantial credit for the final outcome is due to their initial work, even though unfortunately neither leader was able to continue with the project.

The original aim of the project (ACIAR project number FIS/1993/843) was to examine all issues relevant to the sustainability of modern shrimp aquaculture in Thailand. As the project developed, the geographical scope was broadened to include the Asia–Pacific region. As part of this development, a workshop was held in Hat Yai, Songkhla in 1996 and the proceedings of this meeting are published in an accompanying volume (Smith, P.T. ed. 1999. Towards sustainable shrimp culture in Thailand and the region. ACIAR Proceedings No. 90).

By the time of its completion in 1999, the project and its team members had witnessed an interesting and critical period in the shrimp farming industry, both in Thailand and the Asia–Pacific region. The industry in Thailand, for example, reached a peak level of production in 1994–5, and subsequently declined as a result of outbreaks of shrimp viral disease; in response new approaches to management were developed which are now leading to improvements in production. At the same time there have been other major influences, such as the financial crisis in 1997, changes in the international trading situation and an increasingly global emphasis on sustainability issues in shrimp aquaculture.

The first part of this technical report describes the modern shrimp farming industry in Thailand. This sets the scene for the second part: a statistical analysis of a comprehensive survey of shrimp farms in Thailand. Finally, the results of a survey of the Hat Yai workshop participants, based on the major research issues identified during the workshop, are presented and analysed. This process and analysis has resulted in the identification and prioritisation of key issues for research in the development of sustainable shrimp aquaculture in Thailand, and elsewhere in the region.

The members of the project are appreciative of the enormous assistance provided by colleagues in universities, research institutions and the shrimp farming industry. It is a pleasure to acknowledge the funding provided by ACIAR, and the support of the Network of Aquaculture Centres in Asia–Pacific (NACA), the Department of Fisheries of Thailand, and Kasetsart University in Bangkok. The support of the Asian Development Bank (ADB) in providing financial support to the shrimp farm survey is also gratefully acknowledged. This publication is the fruit of the goodwill and combined efforts of all members of the project.

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Grant support for this work came from the Australian Centre for International Agricultural Research (ACIAR), Fisheries Research Institute, Grant Number 93/843. Data from the 1995 Shrimp farm survey were provided by the Thailand Department of Fisheries, the Network of Aquaculture Centres in Asia–Pacific (NACA) and the Asian Development Bank (ADB).

Glossary and Abbreviations

Amphur	The word for district in Thailand.
Baht	The baht is the Thai unit of currency. There are around 35 baht to the Australian dollar (as of May 1998).
BOD	Biochemical oxygen demand
Changwat	The word for province in Thailand
District	Each province in Thailand is sub-divided into districts. The number of districts in each province varies. Also called *amphoe.*
DOF	Department of Fisheries
FCR	Feed conversion ratio
GIS	Geographical information system
NACA	Network of Aquaculture Centres in Asia–Pacific
ppt	parts per thousand
Province	Thailand is divided into 71 provinces. Also called *changwat.*
Rai	The rai is a measure of a unit of land in Thailand. One rai = 1,600 m^2. There are 6.25 rai per hectare.
Shrimp	In Australia and some other countries, marine and brackish-water species of shrimp are usually referred to as a prawns.
SPSS	Statistical Package for Social Scientists

Executive Summary

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Introduction

This report describes the results of a study that was carried out from 1994 to 1999 into the researchable issues in sustainable coastal shrimp aquaculture in Thailand. This was a period in which the shrimp farming industry in Thailand became the world's leading producer of farmed shrimp but also had to confront new shrimp diseases, trade issues and environmental concerns. In many respects, the shrimp farming industry in Thailand has reached a crossroads—the first ten years of the modern industry were characterised by rapid growth, while the last five years have been characterised by stability and even some decline in total production. Peak production occurred in 1994 with 264,000 t, but annual production subsequently declined to an estimated 210,000–234,000 t in 1998, worth US$1,472 million in exports. Recent events suggest that the future for shrimp farming in Thailand, and the region, will depend on the industry's ability to focus on the development of sustainable practices. The aim of this study was to provide industry, researchers and government departments with a contemporary view of the key researchable issues in developing sustainable coastal shrimp culture, based largely on Thailand's experience.

The Objectives

The project commenced in November 1994 with a Workshop in Bangkok that defined the aims and objectives of the study. The scope of the study was broadened during the course of the project to provide a regional perspective and investigate opportunities for linkages within the region. The objectives of the project were as follows.

- To explore relationships between shrimp production and environmental factors for the sustainable utilisation of land and water resources for coastal shrimp aquaculture.
- To use the outputs of objective 1 to identify key researchable issues in sustainable coastal shrimp aquaculture in Thailand and the region.
- To define, in consultation with regional research partners, the scope of a collaborative research project that could address the priority research issues in sustainable coastal shrimp aquaculture identified by the study, and prepare a research proposal to the Australian Centre for International Agricultural Research (ACIAR) for possible funding.

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The 1994 Workshop had a working hypothesis that the pattern of development of shrimp farming in coastal regions of Thailand—involving a period of rapid expansion followed by a decline in many areas—had occurred largely because of environmental problems that impacted on the industry. The 1994 Workshop proposed that the 1995 shrimp farm survey[1] should be used to investigate this hypothesis and that a more comprehensive workshop should be held at a later date to define the researchable issues and prioritise them.

Preliminary Review

In 1995, a preliminary review of the literature was carried out, and the findings form the basis for the chapter which follows (Jenkins et al., this report). In summary, the review found that the Thai shrimp farming industry is highly productive but also faces various constraints which are not always effectively addressed by research. Water quality problems and disease syndromes which cause crop failures have been focused upon by researchers, however, these events are, in most instances, symptoms of underlying constraints rather than the cause of unsustainability. Research is needed to address some of the fundamental constraints, and also to help farmers exploit the opportunities for sustainable development of the industry.

The review identified a total of 25 key constraints that could be addressed by research:

- The relationships between the quality of sediment in ponds, farm management practices and water quality.
- The role of microbial populations in water quality improvement in rearing ponds and the effect of currently used chemicals and probiotics.
- The role of beneficial microbes in controlling pathogenic organisms.
- The role, if any, of a healthy cuticle and gut flora and healthy microbial populations in pond water on enhancing disease resistance in shrimp.
- Identification of industrial and agricultural chemical pollutants in farm source water and identification of their effects on shrimp growth and health.
- Prediction of the occurrence of red tides and identification of reasons for their occurrence.
- Assessment of the capacity of settlement ponds to improve pond influent/effluent water quality. To investigate the efficiency of ponds of different configurations, so as to improve water quality in various production situations.
- Assessment of the capacity of a range of plants and animals to remove wastes from effluent water.
- Examination of the capacity of natural and artificial wetlands to treat effluent water.

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1. The survey was carried out by the Department of Fisheries and the Network of Aquaculture Centres in Asia–Pacific (NACA) with financial support from the Asian Development Bank (ADB).

- Improved understanding of pond ecology so natural production of plankton suitable for shrimp food may be promoted by environmental manipulation.
- Research into naturally occurring immunoenhancers and determination of the reasons for their effect.
- The role of water quality in the development of various diseases.
- Examination of sediment composition and methods of disposal and treatment.
- Development of site assessment procedures to determine areas suitable for farm construction.
- Development of integrated coastal zone management policies.
- Development of methods to remediate land after shrimp farms have failed.
- Identification of appropriate zones for shrimp farming in particular regions so that the environmental carrying capacity is not exceeded.
- Identification of methods of transmitting to farmers current research findings and information regarding farm management practices which are least environmentally damaging.
- Improvement in hatchery techniques.
- Domestication of broodstock so that it is possible to select for desirable inheritable characteristics.
- Research into alternative species (to *Penaeus monodon*) for intensive and semi-intensive culture.
- Experiments with mixed culture.
- Economic rationalisation of the industry with full assessment of environmental and social issues.
- Market price and demand forecasts.
- Research into the social impacts of shrimp farming.

Statistical Analysis of the Farm-based Survey

In 1996, statistical analysis of the data from the Thai shrimp farm survey commenced. Summary statistics were obtained, then various methods were used to investigate associations between variables. Although there were some limitations in the data, the analyses presented in Smith (1999) and Pe and Smith (this report) provide an overview of the key factors affecting sustainability in shrimp aquaculture.

In the first stage of the analysis, summary statistics for the farm survey were determined for 451 farms in 10 provinces of Thailand. There were 877 nominal, ordinal and continuous variables, from which 350 derived variables were calculated (i.e. ratios, indices, rates, percentages and proportions). Next, nine key variables for farm productivity (i.e. key outcome variables) were selected for investigating associations with the other variables in the database. This analysis revealed that there were significant correlations between the key outcome variables and 11 variables for site description, 5 variables for farm management, 9 variables for problem analysis and 18 economic variables. For site description, the province to which the farm belonged was a highly significant factor with regard to productivity. Also, previous use of the land, size of the storage reservoir, growing area, depth of ponds, retention of a mangrove buffer, and use of effluent treatment ponds had significant relationships with the key indices. For farming systems, variables which had significant relationships with key indices were: screening inflow water; applying lime before stocking ponds; applying inorganic fertiliser near harvest; using Thai commercial pellet feed; and sourcing information from extension officers. As for problem analysis, the significant variables were: costs relating to salinity problems; bloom problems; seed problems; lack of experience; water and sediment problems; and disease problems. Significant economic analysis variables were: average price of shrimp; production per hectare; cost of labour; cost of fertiliser; cost of feed; cost of seed; percentage of owner equity; percentage of equity of relatives; culture period; number of crops per year; fallow period; feed conversion ratio (FCR); total male workers; total female workers; and the previous year's profitability.

In the second stage of the analysis, the variables that contributed to the level of shrimp production (kg/ha/yr) were determined by the method of multiple regression. The key variables were: total overheads; total estimated fertiliser cost; total labour cost; total feed cost; seed cost; and total other input costs. Importantly, the analysis confirmed that the shrimp farming industry in each coastal province of Thailand has distinctly different characteristics. Logistic regression analysis was able to identify the variables that play an important part in identifying the provinces. The key variables were: dominant soil type; number of farming years; source of farm water; depth of production ponds; estimated number of other aquaculture farms within 3 km of the farm; number of aquaculture farms sharing the water supply; number of farms discharging effluent into the water supply canal; preparation of an environmental impact assessment; site selection to avoid impacts of other users; design of separate water supply/drainage system; retention of a mangrove buffer zone; use of effluent treatment ponds; existence of water or sediment related problems; and other problems with salinity, feed quality and seed quality. The high proportion of variables relating to environmental aspects of shrimp farming is an important and interesting finding because it provides strong evidence to support the project's hypothesis that environmental factors are of key importance in farm productivity and incidence of shrimp disease.

In summary, if we could simply describe a sustainable farm as one which has high productivity, low problem costs, and reduced impacts on the environment, then the results of the analysis would characterise a small, family farm with a storage pond for inlet water, grow-out ponds that are reasonably deep (i.e. 1.7 m) and with an effluent treatment pond. The farmer would lime ponds before stocking, use Thai pelleted feed, have a low FCR, use a fallowing period to dry ponds and would have access to advice from some form of extension. Further, the farm would be located in an area where the mangrove buffer had been retained, and problems associated with blooms, salinity, sediment and water were relatively low.

From our experience, the geographical information system (GIS) was a useful tool for presenting and investigating associations in the data and future surveys should use global positioning system (GPS) techniques to increase the application of the results. Also, it may be better to use 'pond' rather than 'farm' as the sample unit.

The Workshop at Hat Yai, Songkhla

A Final Workshop was held in Hat Yai, Songkhla, in October 1996. At that Workshop, 12 countries were represented and research work was given in 28 papers. The papers were presented in seven sessions that focused on: the status of shrimp farming, farmer's issues, research issues in Asia–Pacific, shrimp disease and health management, environmental management and integration into coastal zone planning, and social impacts, economics and trade. The edited papers from the Workshop have been published separately (Smith 1999).

Essentially, the presentations reinforced the following points:

- Results of research studies often had not reached the farm, suggesting that extension work was inadequate.
- The occurrence of problems such as yellow head, white spot and other shrimp diseases were symptoms rather than causes of non-sustainability, suggesting that management of environmental impacts and improved methods of pond management were the major issues confronting the shrimp industry.
- Better practices could be adopted to minimise the spread of contagious diseases, such as checking larvae for disease with genetic tests, minimising transfer of disease by carriers, and adopting closed-cycle systems.
- The shrimp industry differed from other methods of farming in that the reproductive cycle was not complete, indicating that improved methods of animal husbandry depend on developing methods for maintaining domesticated broodstock and raising their young.

The speakers at the Final Workshop focused on their own field of expertise and related this to the issue of sustainability. Discussion sessions at the Workshop used the papers as stimulus for examining research issues. A total of 122 research issues were identified and categorised at the Workshop.

Prioritising Research Issues for Sustainable Aquaculture

The issues that were defined at the Final Workshop in 1996 were developed into a questionnaire that was sent in September 1997 to all Workshop participants. The analysis of the survey results provided the project with a means of prioritising and updating the research issues for sustainable aquaculture. The findings are reported in Smith and Phillips (this report).

A total of 25 participants from six countries responded to the survey. The 122 researchable issues identified at the workshop were categorised into eight areas: disease and health; environmental impact assessment and monitoring; feed and nutrition; genetics and broodstock; farm and pond management; remediation of disused farms and damaged habitats; socioeconomics, trade and licensing; and information transfer and training. The three most important areas for research funding were disease and health, farm and pond management, and genetics and broodstock. Participants considered that the three greatest constraints to sustainability in their own countries were viral diseases, poor pond management, and self-pollution. The same constraints were identified for the Asia–Pacific region, suggesting that there is good scope for intra-regional research projects and linkages with related projects.

In addition, the researchable issues were characterised in terms of: impact on productivity; achievability; importance; on-going research; target of research; and priority ranking for the research. The priority for each researchable issue was determined by scoring them on a scale from 1 to 10 (with issues of highest priority receiving a score of 10). In the scoring process, 'genetics and broodstock' was the area which participants gave most support, with 79% of its issues receiving a median score of ≥6. Eleven issues received the highest ranking, with a median score of ≥8. The issues were from five of the eight areas of research and they received broad support from participants from across the Asia–Pacific region. The 11 priority issues for research were:

- to develop high health, low risk pond management methods;
- to develop practical methods of immunoprophylaxis for shrimp;
- to investigate interactions between nutrition and shrimp health;
- to assess causes of water quality deterioration and the effects on shrimp health;
- to assess effluent management and waste treatment technologies;
- to investigate endocrinology of broodstoock maturation;
- to develop techniques for sustainable broodstock supply, preferably with domesticated broodstock;
- to develop high health hatchery production methods;
- to study pond dynamics and pond ecology;
- to better control the pond environment through biological agents and microbial ecology; and
- to develop cost-effective training and technology transfer methods and approaches to overcome inadequacies in transfer of information from research to farm.

Conclusions

The project began with the objective of producing a contemporary assessment of the key researchable issues in coastal shrimp farming in Thailand. The working hypothesis that environmental problems are the cause of reduced productivity and incidence of disease in shrimp farms in Thailand has been strongly supported by the findings of the study. Also, recent problems with diseases and the environmental suggest that the future of shrimp farming in Thailand and the region will depend on the industry's ability to develop sustainable practices. The three most important areas for research were identified as studies into: disease and health; pond and farm management; and genetics and broodstock. A total of 122 key research issues were targeted and prioritised for assisting in the development of sustainable coastal shrimp culture in Thailand and the region. Encouraging linkages in intra-regional research projects was identified as being important in enhancing the progress in and dissemination of findings from such research.

Reference

Smith, P.T., ed.. 1999. Towards sustainable shrimp culture in Thailand and the region. ACIAR Proceedings No. 90. Canberra, Australian Centre for International Agricultural Research (in press).

An Assessment of the Status of the Shrimp Farming Industry in Thailand

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Abstract

The shrimp aquaculture industry in Thailand has expanded greatly over the last two decades. There was a rapid expansion from 1988 to 1995 but more recently shrimp production has decreased and stabilised at around 234,000 t in 1998. In this chapter, the development of the shrimp farming industry in Thailand is reviewed.

The development of shrimp farming in Thailand has generated substantial foreign revenue from shrimp export, and associated industries have provided economic boosts to the Thai economy. In rural areas, this has often resulted in improvements in infrastructure, such as roads and electricity supplies. Nevertheless, environmental degradation has occurred where farms were located in unsuitable sites and where farm densities exceeded the carrying capacity of the environment. Although many have benefited financially through farm ownership or industry employment, there are cases where some have been disadvantaged or displaced by the industry.

This review finds that research has often neglected many of the problems and issues that are faced by the shrimp farming industry. Much of the past and ongoing research efforts have been largely directed toward solving production problems as they have arisen. Instances of crop failure have commanded the attention of most researchers, and hence water quality problems and disease syndromes have been focused upon. However, these crop failures are, in most instances, symptoms of underlying problems rather than the cause of unsustainability. Hence, this review tries to identify key researchable constraints to development of a sustainable industry with the assistance of many eminent people in Thailand, thus generating a list of 25 key issues for research.

Finally, many of the constraints and issues that have been identified are interrelated or interdependent. This suggests that collaboration between researchers and linkages between projects will be essential to developing a sustainable shrimp farm industry. Hence, it is necessary for all those currently concerned with developing a sustainable shrimp farm industry in Thailand to identify the gaps in the research efforts and to formulate a coordinated and integrated approach to future research. This approach must be fitted within the framework of the existing research bodies in Thailand. The benefit to Thailand of regional cooperation in such research is also recognised.

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Shrimp Farming in Thailand

Over the last two decades, Thailand's coastal shrimp aquaculture industry has expanded dramatically, providing considerable economic benefits for farmers and the diverse industries which service and support shrimp farming. Export of shrimp and shrimp products has earned the country substantial foreign revenue. However, industry expansion has not been without problems and there is concern within the Government, the industry and scientific communities that farm viability is threatened by a combination of poor management practices, pollution by farm effluent and viral diseases. These fears are founded on the experiences of 1988 in the once thriving shrimp aquaculture industry in Taiwan (Liao 1989; Lin 1989; Chen 1990), the extensive crop losses in China in 1993 (Anon. 1994c), the losses sustained by Vietnamese shrimp aquaculturalists (Anon. 1994b), and recent declines in annual production in Thailand and other countries in the region (Flegel 1996; Funge-Smith 1997; Anon. 1998a,b).

In view of these concerns and problems, this study assessed the current state of the shrimp farming industry in Thailand, examined factors contributing to farm problems and identified researchable constraints to the development of a sustainable industry. The specific aims of the study were:

1. to examine the current practices of the shrimp farming industry in Thailand, the history of the industry's development and the goals and policies of the Thai government regarding the industry;
2. to examine current concepts of sustainable development and assess research into shrimp aquaculture; and
3. to identify key researchable issues which researchers have not yet addressed and which are impeding development of a sustainable shrimp farming industry in Thailand.

What is sustainable shrimp aquaculture?

For farmers, investors and government agencies concerned with financial expansion and export revenue, sustainability of shrimp aquaculture focuses on the maintenance of at least the current level of production and income. The desirable situation for most investors is to see an increase in financial returns over time, keeping up with, or ideally, outpacing alternative investments. Industry expansion or intensification of production may be needed to achieve this.

For those who are concerned primarily with environmental conservation, sustainable shrimp aquaculture refers to shrimp production which has minimal negative impacts on the environment and can be maintained at a level which does not cause progressive environmental degradation.

The failure of shrimp farms in Taiwan, and more recently in parts of Thailand and elsewhere, was attributed to a deterioration in environmental conditions. This has forcibly brought to the attention of the industry that sustainable financial returns will only be achieved if environmental concerns are addressed. This coincides with the beginning of a worldwide recognition that the natural environment imposes constraints on the size of economic systems and that ignoring these constraints may ultimately lead to economic collapse.

Any attempt to identify research issues which may address the overall sustainability of shrimp farming as an industry must first fully consider the concepts of sustainability as they are currently evolving in scientific, economic, social and political circles. This is done later in this chapter (sustainability issues section), together with an appraisal of the performance of researchers and the government in addressing the issue, and an evaluation of current industry practices in view of these concepts.

Thai coastal resources

Thailand is located in the tropical zone between latitudes 6–21°N and longitudes 98–106°E. The wet season generally occurs from April to November, with monthly rainfall in southern Thailand increasing from 36 mm in the driest month of January to 328 mm in the wettest month of September (Funge-Smith 1997). The total land area is 51,300 km^2, bounded in the north, west and east by mountain ranges and in the south by the South China Sea and the Andaman Sea. The coastline is approximately 2,600 km in length. There are five major rivers, four of which flow through the densely populated areas of the Central Plain and drain into the Upper Gulf of Thailand. These are the Chao Phraya, the Mae Klong, the Ta Chin and the Bang Pakong Rivers. The fifth river, the Tapi River drains into Ban Don Bay in the south.

In recent years, rapid population increases—coupled with industrial, agricultural, aquacultural and fishing activities—have resulted in degradation of the natural coastal resources. Many areas are experiencing the effects of water pollution, mangrove losses and encroachment by urban settlements (Paw et al. 1988).

Shrimp production

Figure 1 shows the coastline and shrimp farming areas of Thailand. Table 1 shows that Thailand is currently the world's largest producer of cultured shrimp (Funge-Smith 1997). This has been achieved over the last two decades following dramatic industry expansion and in tensification of production. Between 1976 and 1991, the area covered by shrimp farms increased at a rate of 14.7% annually and the number of shrimp farmers rose by 21% per year. In 1976, there were 1,544 shrimp farmers and farms covered 76,850 rai (12,300 ha) (NACA 1994a); by 1994, there were 72,000 ha, divided into around 22,000 farms (Anon. 1995b) (see Table 2). Since then, production has declined and the area used for farming has stabilised. The production in 1998 was estimated at 220,000 t.

Also, farming methods initially became more intensive, producing more shrimp per unit area. From 1987–1994 there was more than a six-fold increase from 0.45 t/ha/yr to 2.81 t/ha/yr. However, in 1997 productivity fell to 2.14 t/ha/yr (Funge-Smith 1997), then increased to 3.0 t/ha/yr (Anon. 1998b). Currently, 80% of farms use intensive methods, 15% semi-intensive and the remaining 5% traditional extensive methods (Funge-Smith 1997).

In 1972, 67,878 t of shrimp were produced, with only 1.5% (991 t) from culture. In 1991, 268,565 t were produced, with 60.3% (162,070 t) from culture (NACA 1994b). Production from culture peaked at 72.5% (263,945 t) in 1994 (Anon. 1995b), but then dropped back. In 1997, 62.8% of the shrimp production was from culture (Funge-Smith 1997). The annual production figures for this period are given in Table 3.

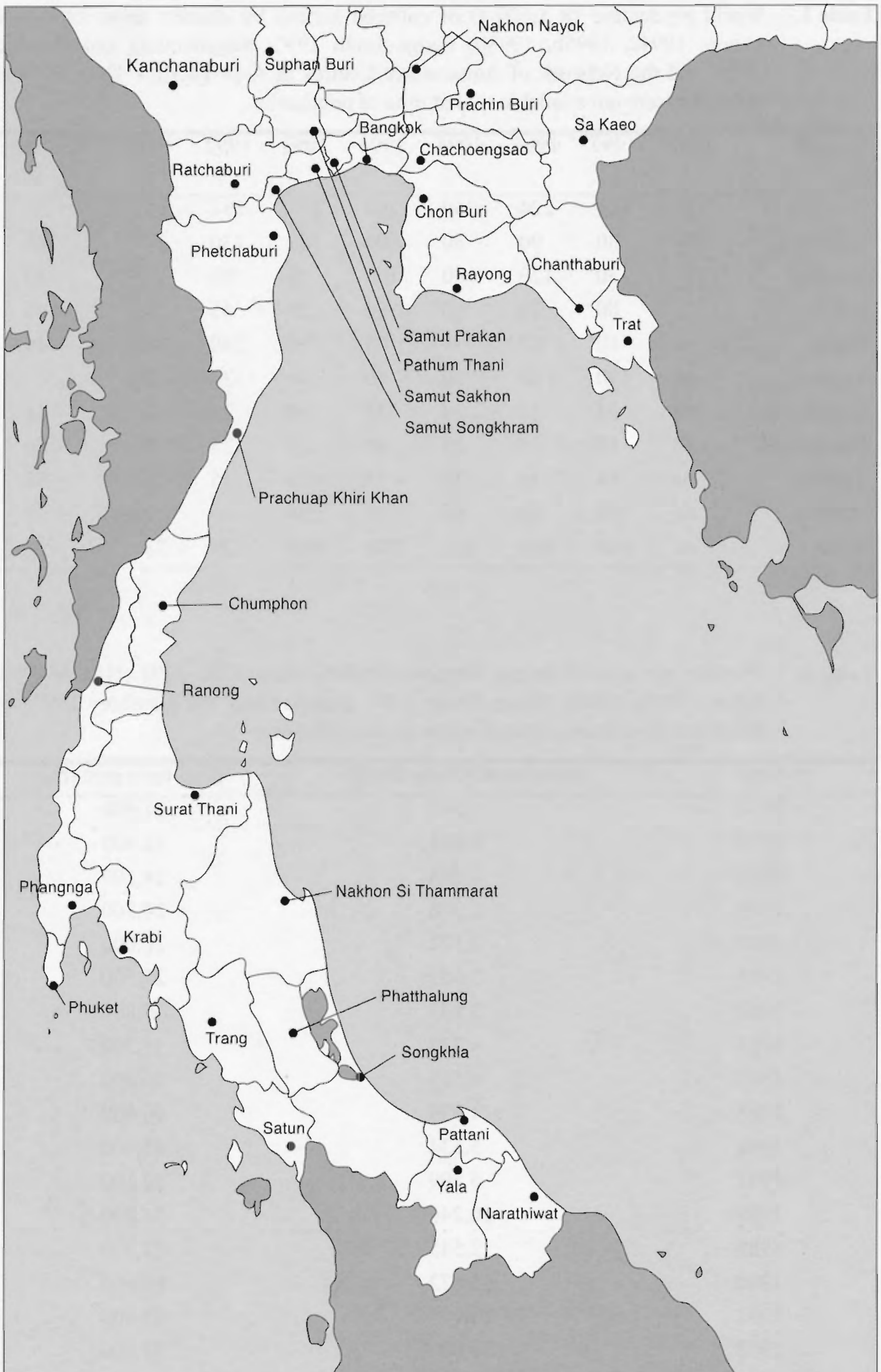

Figure 1. The shrimp farming regions of Thailand

Table 1. World production (× 1,000 t) of cultured shrimp by country from 1991–1997 (Anon. 1994c, 1995b, 1998b; Funge-Smith 1997; Ragunanthan and Hambrey 1997; and the Network of Aquaculture Centres in Asia–Pacific). Data for some countries were not available (na) at time of publication.

Country	1998	1997	1996	1995	1994	1993	1992	1991	% change 97/91
Thailand	234	219	224	259	264	225	184	162	+ 35
Indonesia	50	80	90	80	100	100	130	140	– 43
Ecuador	130	130	120	100	100	76	95	100	+30
India	70	80	70	60	70	55	45	35	+ 64
China	na	80	80	70	35	30	140	145	– 45
Vietnam	na	30	30	50	50	40	35	30	-
Bangladesh	na	34	35	30	35	30	25	25	+ 36
Philippines	35	10	25	25	30	25	25	30	– 66
Taiwan	na	14	15	15	25	20	25	30	– 53
Other	na	52	68	62	93	54	46	45	+ 15
Total	na	660	693	712	733	644	729	733	– 10

Table 2. Number and area of shrimp farms in Thailand from 1976–1998 (NACA 1994a; Anon. 1995b, 1998b; Funge-Smith 1997; Ragunanthan and Hambrey 1997; and the Network of Aquaculture Centres in Asia–Pacific).

Year	Number of shrimp farms	Total farm area (ha)
1976	1,544	12,300
1977	1,437	12,400
1978	3,045	24,200
1979	3,378	24,700
1980	3,572	26,000
1981	3,657	27,500
1982	3,943	30,800
1983	4,327	35,500
1984	4,519	36,800
1985	4,939	40,800
1986	5,534	45,400
1987	5,899	52,100
1988	10,246	54,800
1989	12,545	71,200
1990	15,072	64,600
1991	18,998	75,400
1992	19,000	73,000
1993	20,000	71,000
1994	22,000	72,000

Table 2. (cont'd) Number and area of shrimp farms in Thailand from 1976–1998 (NACA 1994a; Anon. 1995b, 1998b; Funge-Smith 1997; Ragunanthan and Hambrey 1997; and the Network of Aquaculture Centres in Asia–Pacific).

1995	26,000	74,000
1996	22,000	69,000
1997	21,000	69,000
1998	22,500	70,400

Table 3. Total marine shrimp production in Thailand from 1972–1998, and the quantities and percentage produced by aquaculture and sea capture for each year (NACA 1994b). Aquaculture production of shrimp in tonnes from 1992–1998 (Anon. 1994c, 1995b, 1998a,b; Funge-Smith 1997; Ragunanthan and Hambrey 1997) (na = data not available).

Year	Total production	Production from capture	Production from culture	% of production from culture
1972	67,878	66,887	991	1.5
1973	79,160	77,525	1,635	2.0
1974	81,868	80,093	1,775	2.1
1975	87,039	84,501	2,538	2.9
1976	88,677	86,139	2,538	2.8
1977	118,953	117,363	1,590	1.3
1978	127,404	121,009	6,395	5.0
1979	116,456	109,392	7,064	6.1
1980	118,340	110,277	8,063	6.8
1981	133,435	122,707	10,728	8.0
1982	166,614	156,523	10,091	6.0
1983	139,134	127,584	11,550	8.3
1984	117,401	104,393	13,007	11.1
1985	107,472	91,631	15,841	14.8
1986	120,413	102,413	17,886	14.8
1987	129,777	106,211	23,566	18.1
1988	141,503	85,870	55,633	39.3
1989	178,699	85,204	93,495	52.3
1990	200,724	82,497	118,227	58.7
1991	268,565	106,495	162,070	60.3
1992	276,500	91,616	184,884	66.9
1993	321,085	95,571	225,514	70.2
1994	363,446	100,000	263,945	72.5
1995	364,540	105,000	259,540	71.2
1996	364,000	140,000	224,000	61.5
1997	349,000	130,000	219,000	62.8
1998	na	na	234,000	na

Domestic and world demand

Japan is the most important market for Thai cultured shrimp, followed by the United States of America. Smaller quantities are exported to Singapore, Italy, Australia and Hong Kong (NACA 1994a).

From 1980–1990, the domestic consumption of shrimp fell at an average rate of 0.07% a year, a decrease attributed to the increase in prices over that period. In the 1990s, the amount of shrimp consumed by the Thai people is increasing, including both cultured and capture animals. The proportion of cultured shrimp has increased as the annual income of many Thai people changes with economic conditions. Additionally, further expansion of the tourist industry has the potential to increase domestic demand (K. Pyakuryal, pers. comm.).

Economic importance

Cultured shrimp is the 'number one' export earner from the primary production sector and fourth overall, following textiles, computers and appliances, and gemstones (T. Jitsanguan, pers. comm.). Thailand exported 32,960 million baht (US$2,200 million) worth of shrimp in 1993 (Anon. 1994a) and 40,000 million baht (around US$2,600 million) in 1994 (Anon. 1994a). Exports from shrimp production were worth US$1,472 million in 1998 (Anon 1998a).

Incentives for interest in shrimp farming

Investors and farmers have been attracted to shrimp farming by relatively fast and potentially high economic returns. Compared to production of agricultural crops such as rice, corn, tapioca, coconut or palm oil, large sums can be made (NACA 1994a). In Chantaburi Province, for instance, the annual income from agricultural land was estimated at 30,000 baht/rai before conversion to shrimp farming; after this occurred, it rose to 100,000–400,000 baht/rai (NACA 1994b).

There are also long-term economic benefits. Land values often increase in areas where shrimp farming has gone ahead, providing added investment incentive and 'insurance' against financial losses in the event of crop failure. Land prices in Chantaburi rose from 200–500 baht/rai prior to shrimp farming, to 5,000–10,000 baht/rai by 1990. Also, Funge-Smith (1997) explained that the economic boost to rural areas in the wake of shrimp farming includes the provision and improvement in roads, electricity, other infrastructure and education of children.

History of shrimp farming in Thailand

Shrimp farming has been practised in Thailand for around 55 years (Tookwinas 1993). The traditional method of production was similar to what is now called 'extensive' farming. Shrimp fry were trapped in the salt beds and paddy fields around estuarine areas and harvested when mature. The proliferation of shrimp farms began in 1972 when the Department of Fisheries (DOF) began to promote recently developed technologies and intensive culture (Katesombun 1992). The expansion was partially facilitated by the development of hatchery technology in the late 1960s (Liao 1990) which allowed the production of large numbers of larvae for stocking ponds.

Although Thailand has many shrimp species suitable for culture, the most popular ones are the banana shrimp, *Penaeus merguiensis*, and the tiger shrimp, *P. monodon.*

The latter species is particularly popular as it is relatively resistant to environmental changes, has a high growth rate and a high economic value on export markets (NACA 1994a).

The current systems of shrimp production are classified as extensive, semi-intensive, and intensive, according to their stocking levels and pond size (NACA 1994a). However, it should be mentioned that Chanratchakool et al. (1998) prefer to use high yield (over 3 t/ha/crop) and lower yield (1–3 t/ha/crop) to describe the culture systems. The systems used in this report are as follows.

Extensive culture

The extensive system, the traditional system for shrimp aquaculture, produces mostly banana shrimp. Stocking relies on the shrimp larvae that are naturally present in seawater to initially fill ponds. Density is usually between 2–5 shrimp/m^2. The natural productivity of the water provides food for the shrimp and sometimes animal manures and chemical fertilisers are added to pond water to accelerate the growth of plankton and sediment-dwelling micro-organisms. Pond size is 50–100 rai. Although a small number of farms use water pumps, the system depends predominantly on the channelling of water in and out with the tides, controlled by sluice gates. By necessity, ponds are close to a canal or the sea. The rate of water exchange is usually around 10–15% of the pond volume per day. Cultivation takes 3–4 months, there are usually two crops per year, and production varies from 310–1,560 kg/ha/year (NACA 1994a). The estimated cost of production is about 50–75 baht/kg (NACA 1994a) or US$1–3/kg (Funge-Smith 1997).

Semi-intensive culture

This system uses ponds of around 15 rai. The shrimp larvae naturally present in the seawater are supplemented with hatchery-grown larvae to a stocking density of between 5–30 larvae/m^2. Paddle aerators are used to maintain adequate oxygenation of the water, and pumps facilitate water exchange. Predator and pest elimination is carried out as necessary. Cultivation takes between 4–6 months, allowing two crops per year. Production levels are between 1,800–3,125 kg/ha/year and the cost of production was estimated in 1993 at 75–125 baht/kg (NACA 1994a) or US$2–6/kg (Funge-Smith 1997).

Intensive culture

Intensive culture practices are aimed at highest possible production from a given area to achieve maximum profit. Shrimp farms using intensive production methods produced around 90% of the total annual farm harvest in Thailand in 1991. Shrimp larvae from hatcheries are stocked at 30–150 shrimp/m^2. The survival rate is generally between 44–60% of this. Addition of feed to the pond is essential, and all factors affecting production—such as water quality, water exchange and aeration—require constant monitoring and regulation. The rate of water exchange is about 30% per day. The pond size is usually about 4 rai (0.65 ha). The production cost has been estimated to be 123–128 baht/kg or US$4–8/kg (Funge-Smith 1997) and the production per rai, 7,250 kg/ha/year (Office of National Statistics 1990).

Intensification of farms has been encouraged by DOF as a method of improving existing land use. However, this has not always proved possible in cases where farmers lack technological expertise, have insufficient finance to make modifications to their operation, or where the original extensive sites are unsuitable (Kapetsky 1987; Csavas 1988).

Geographic distribution of shrimp aquaculture

Shrimp farming is most widespread along the coastal regions of the Gulf of Thailand and is currently expanding into areas along the south-western coast adjacent to the Andaman Sea. Figure 1 shows the main shrimp farming areas and the provinces of Thailand. According to Jitsanguan et al. (1993), the first areas to be developed for intensive shrimp production were the Upper Gulf provinces of Samut Songhkram, Samut Sakhon and Samut Prakhan, where traditional, extensive farms were replaced by intensive farms. This occurred in the mid-1970s and was actively promoted by DOF. By the late 1980s, farmers from this area faced declining production and moved to the east of the country, particularly to the provinces of Cholburi, Chantaburi and Trat. In the late 1980s, shrimp farms began to develop on the south-eastern coast. Regions with particularly high farm densities are the provinces of Nakhon Sri Thammarat and Songkhla. Since 1994, these areas have experienced problems, with production of farms in the southern areas reportedly declining due to disease outbreaks (Anon. 1995a; Flegel 1996; Funge-Smith 1997).

In the latter half of the 1990s, most farmers have adopted various strategies for disease control to cope with viral diseases, such as white spot and yellow head. Also, farms have been set up inland—in some cases in freshwater areas (Ragunathnan and Hambrey 1997).

Changes in viability of farms

A combination of factors has lead to changes in productivity and economic viability of shrimp farms in Thailand. In the Upper Gulf in the late 1980s, factors included:

1. Pollution of farm water supplies with water containing the domestic, industrial and agricultural wastes of the Bangkok area and other areas of the watershed. (The four major rivers that drain into the Upper Gulf are known to be significantly polluted with such waste, and tidal movements result in poor flushing of the wastes from the inshore areas.)

2. Self-pollution of water supplies by the shrimp farms. Where there are high densities of intensive farms with inadequate separation of source water from effluent water, the quality of the water in the ponds deteriorates, leading to stress in the shrimp and consequently disease.

After a peak in farm yields in 1989, production in the Upper Gulf dropped dramatically. Affected areas were Samut Prakhan, Bangkok, Samut Songhkram, Samut Sakhon and Petchaburi (Phillips 1992). In Samut Sakhon Province alone, 22,220 rai previously under intensive culture were abandoned after a deterioration in environmental conditions. Approximately 80% of these farms were idle in 1994 (NACA 1994a). Many farms were converted back to traditional extensive farms or are in the process of conversion. Some farms are now the sites of large-scale residential developments, while others have been excavated to provide soil for these projects.

The national level of shrimp production has been maintained by the increase in the number of farms and increased production along the eastern and southern coasts. However, farms in these areas have also experienced problems of environmental degradation (DOF 1994) resulting in production decreases (Funge-Smith, cited in Briggs and Funge-Smith 1994). Since the mid-1990s, the regular occurrence of white spot disease has seriously impacted on farm productivity and has caused the closure of farms in some areas (Flegel 1996; Funge-Smith 1997).

The pattern of expansion and intensification of shrimp farming followed by disease problems has been seen elsewhere in the world. In Taiwan in 1988, annual production dropped by over 75% from the previous year (Lin 1989), and between September and mid-December 1994, US$64 million worth of shrimp were lost in two provinces in Vietnam. Government officials there attributed the losses to disease outbreaks resulting from unplanned and spontaneous shrimp culture (Anon. 1994b). China has also experienced serious shrimp crop losses.

Diseases in the Thai industry

The mortality of shrimp in Taiwan in 1988 was attributed to bacterial and viral diseases which were exacerbated by a number of non-pathogenic factors. These were:

- degradation of culture ponds;
- an increase of stocking densities to unreasonably high levels;
- defects in formulated feeds;
- indiscriminate use of antibiotics and medicines;
- inadvertent or unavoidable use of polluted water;
- lack of technical training of shrimp farmers; and
- absence of a reliable system of sanitation (Chien 1992).

Shrimp disease outbreaks have occurred in Thailand in the 1990s (Flegel 1996; Funge-Smith 1997; Anon. 1998b). In a Network of Aquaculture Centres in Asia–Pacific (NACA 1994a) survey, 75% of farmers stated that they had had problems with shrimp diseases. Of these, 25% reported yellow head, 22% one-month death syndrome, and 21% black gill disease. Other reported diseases were swollen gill, black splinter, red body, tail rot and crooked leg diseases. Of the surveyed farmers, 46% had problems with disease twice per crop, 36% once per crop, and 17% once a year. There was a higher incidence of particular diseases depending on proximity to either the sea or a canal. This was considered suggestive of a relationship between these diseases and water quality (NACA 1994a). Yellow head and red body disease were most commonly encountered at farms using canal water. Black gill and one-month death syndrome were most common near the sea. Since 1994, white spot virus has been a major cause of disease in Thailand, as in other countries in the region (Flegel 1996).

Disease-causing organisms are probably widespread and abundant in shrimp under culture conditions even in the absence of disease. Studies in Indonesia found no significant difference between the bacterial population in the canals supplying both farms which had failed and those which had successfully operated extensive and semi-intensive systems (Kakorkin and Sunaryanto 1994). Research by the Aquastar Company showed that postlarvae supplied to their farms by hatcheries commonly have pathogenic organisms associated with them (Fegan 1994).

Pathogens cause disease if shrimp are stressed. Stress alters the internal biochemical balance of the animals, leaving them susceptible to infection (Shariff and Subasinghe 1992). In shrimp farms, factors which cause stress to shrimp are overcrowding and poor water and sediment quality. In recognition of the role of poor water quality in the development of disease in shrimp, farmers often change their water as soon as they see evidence of poor health in their animals. This triggers moulting, a phase during which the shrimp are particularly sensitive to the state of the surrounding environment. Problems with the sediment quality can then induce worsening of the existing disease syndrome, and may lead to death. This sequence of events may be responsible for a number of the crop failures that farmers attribute to intake of polluted water. Rather than an acute problem triggered by properties of the exchanged water, the problem was a chronic one, the result of poor pond condition (J. Turnbull, pers. comm.).

Disease diagnosis is difficult since ill health in shrimp cannot be diagnosed easily by observation of external signs or behaviour. Laboratory techniques are most useful but even these are not always successful unless the disease condition is severe (Turnbull 1993). Laboratory diagnosis techniques often take 3–4 days, by which time the disease may be well advanced or have resulted in mortalities. New faster techniques, such as polymerase chain reaction (PCR) techniques, are being developed.

Research efforts are improving the knowledge and management of particular diseases. Yellow head disease caused a loss of an estimated 20–25% of production in Thailand in 1992 and early 1993. A coordinated response by industry, academic and government sectors helped to limit the spread of the disease. The causal organism was identified by research at the National Institute for Coastal Aquaculture as a new virus, subsequently named yellow head baculovirus (Fegan 1994).

All research dealing with disease in shrimp recognises the need for a well managed pond system to reduce the incidence of disease and to allow treatments and control measures to be effective. The greatest progress in disease management can be made by the use of good management and husbandry to improve the culture environment as emphasised by Chanratchakool et al. (1994).

Local Socioeconomic Impacts of Shrimp Farming

Positive economic and social impacts

Shrimp farming has generated employment both on farms and indirectly through servicing industries. These industries include hatcheries, feed plants, transportation operations, and freezing and cold storage plants, as well as manufacturers of products such as paddle wheels for pond aeration, containers for shrimp storage and transport, hatchery tanks, water pumps, chemicals for water treatment, and chemotherapeutics for disease control. In 1994, the shrimp culture industry employed around 97,000 people directly and 53,000 indirectly (DOF 1994).

It has been suggested that employment created by shrimp farming has, to an extent, stopped the movement of local people to Bangkok and other large cities and has led to an overall economic improvement in the purchasing power and savings of rural people (NACA 1994a). The expansion and upgrading of roads, electricity supplies, municipal water supplies, telephones and other communications, and transportation have also been attributed to shrimp production (NACA 1994a; Funge-Smith 1997). Data from the districts of Ranot and Hua Sai (Piamsomboon 1993) appear to support this. Of the shrimp farmers surveyed there, 86% perceived that trading in villages in the area had expanded as a result of shrimp farming and that changes in the infrastructure supporting the villages and farms had occurred. It was concluded from these data that there appeared to have been an overall generation of wealth and improved social and economic conditions in the districts as a result of the expansion of shrimp farming. However, Piamsomboon (1993) indicated that 40% of all farmers (not just shrimp) did not perceive the socioeconomic changes in the area to be positive. Further research into this sector of the shrimp farming community may provide a better insight into these changes.

Negative economic and social impacts

Although the shrimp culture industry has a record of impressive production and export revenue figures, and many have profited from the industry, there are also those who have been displaced by and suffered because of its expansion. These people, because of their lack of influence, monetary power and in many cases education, have a low profile when assessments of the industry are made. The popular press of Thailand frequently reports on these people (e.g. Raksakul 1994). In the south, there have been conflicts among shrimp farmers and confrontations between shrimp farmers and other local farmers and residents over the discharge of effluent water into the public waterways and coastal seas, the intrusion of saline water into rice fields and the salinisation of canals (Jitsanguan et al. 1993).

The conversion of land from agricultural production to shrimp farming is an economic loss to the agricultural sector. In a survey of shrimp farms in southern Thailand, Piamsomboon (1993) found that prior to use for shrimp, 49% of the land had been rice paddy and 27.5% orchards (NACA 1994a). Additionally, land can be lost to agriculture as a consequence of environmental changes induced by shrimp farms. In the early stages of development, mangrove forests were lost to construct shrimp farms which may have affected local people. Most mangrove forests are communally used resources from which products for subsistence and for sale are harvested. The value of these products was calculated by Bannarlung (1990) to be 14,700 baht/rai/year. Whilst this amount is substantially below the returns from shrimp farming, loss of this resource means that it may have been necessary for some people to find substitute ways of obtaining income, food and other products. Recently, however, significant progress has been made to reducing the loss of mangroves to shrimp farms (Funge-Smith 1997).

There is a need for a comprehensive economic assessment of the long-term costs and benefits of shrimp culture (Jitsanguan et al. 1993).

Production Practices and Techniques

The production methods and management practices of shrimp farms vary between areas and between individual farms. Furthermore, the methods employed by each farmer are necessarily dynamic, governed by the changing condition of the shrimp, the water quality of the ponds, and by the acquisition of new knowledge. This lack of consistency makes it difficult to describe the exact practices involved in shrimp farming. Instead, an overview of techniques and principles is presented here. As intensive farming produces most of Thailand's shrimp, this method of production is given the most attention.

Larvae and hatcheries

The development of hatchery techniques in the late 1960s (Liao 1990), together with successful induction of spawning in tiger and banana shrimp in 1973 (Suraswadi 1990) allowed shrimp farmers to increase stocking densities and consequently production. Prior to this, only wild seed stocks were available which were not always reliable. At present, very few farms use wild-caught postlarvae in Thailand (M.J. Phillips, pers. comm.).

In Thailand in 1989, there were 2,000 private hatcheries producing an estimated 12,100 million shrimp juveniles (Suraswadi 1990). In 1997, there were an estimated 1,000 hatcheries (Funge-Smith 1997). Government fishery research stations are also involved in the production and supply of postlarvae. Concrete tanks or shallow ponds made of bricks are generally used, allowing minimal costs for construction and operation. Other operations use fibreglass tanks. Hypersaline water is often obtained from salt pans—this is relatively free of pathogens because of its high salinity. The survival rate in hatcheries may be as high as 95% (Suraswadi 1990), however it is usually between 40–50% in small-scale hatcheries.

Juveniles are purchased by farmers at between 10 and 30 days after moulting to the postlarvae stage (PL10–30), but usually between 14 and 18 days (PL14–18) (NACA 1994a). In 1997, prices for PL12–15 were US$3.43 to US$4.06 per thousand (Funge-Smith 1997).

Stocking density

Stocking density is determined by a number of factors including pond size, quality of the available water supply, the type of technology used by the farm and the level of production desired. The goal of the farmer is, understandably, to achieve the greatest possible production to maximise profits. In many instances, farmers stock their ponds at a very high density initially with the intent to offset losses incurred later. A particular stocking density, however, does not ensure a particular output (NACA 1994a) as mortality rates vary. Reasons for this include death of larvae from the stresses induced by transport or disease or—at later stages in growth—from disease or from syndromes related to deterioration of water quality. A study by Chaiyukum et al. (1992, cited in NACA 1994a) found a very variable survival rate between the time of initial stocking of ponds and harvest (25.9–81.5%), even with a relatively low stocking density of 25 shrimp/m^2.

Pond carrying capacity

The carrying capacity of a pond is generally defined as the maximum density of shrimp which can be supported by the pond environment whilst maintaining optimal shrimp health and growth rates. The pond's carrying capacity is naturally a function of the capacity of the environment surrounding the pond to assimilate its wastes and to cope with its other environmental impacts (see below—section on impacts of shrimp farms). Stocking densities in excess of the pond's carrying capacity lead to lower production levels, and in the event of severe deterioration in environmental quality, crop loss from disease. The carrying capacity varies depending on numerous factors, including features of the pond site, water quality and exchange, and pond management practices.

Analysis of data from detailed crop histories by Corpron (cited in Fegan 1994) established that beyond a density of 6 t/ha/crop there was a marked reduction in feeding and growth rate. Based on these data, rather than specifying a desirable stocking density, the Aquastar Company directed its farmers to limit production to 6 t/ha/crop as a measure toward the goal of achieving sustainable production (Fegan 1994). If the pond is densely stocked, the company recommends that at least partial harvest be performed when this level is reached; the remainder of the shrimp can be harvested later when at a larger size. Hirasawa (1992) also identified 6 t/ha/crop as an upper limit for production in a study of feed conversion ratios (FCRs). Above this stocking density, FCRs began to increase sharply. He attributed this to a critical change in the ecology of the pond which occurs at higher stocking densities, adversely affecting natural pond productivity (i.e. the growth of plankton on which shrimp feed). Despite these findings, some farmers harvest 9–12 t/ha/crop (DOF 1994). There is clearly a need to carry out research in order to better understand the interactions of pond dynamics, pond microbiology and productivity.

Water supply and quality

In general, water used for shrimp rearing should be within the temperature and salinity ranges suitable for the species under culture and be free of industrial and agricultural pollutants (Apud et al. 1989). The source of the water supply varies depending on the farm location and the distances over which water must be pumped. Extensive farms rely on tidal inflow, while semi-intensive and intensive farms pump water from canals (called *khlongs* in Thailand), estuaries or the sea. Effluent water may be discharged into the same water body from which water is taken. Where there is limited drainage or tidal flushing of that water body, water quality is likely to be poor. Such conditions may account for a disparity in income found between shrimp farms using water from different sources in a survey undertaken in the Ranot District (NACA 1994a). There, farms obtaining water directly from the sea earned an average income of 81,277 baht/rai/crop while those using canal water earned only 30,263 baht/rai/crop.

Early shrimp farming operations required the use of brackish water. It was believed that a salinity of 12–25 parts per thousand (ppt) was necessary for shrimp survival. Scarcity of water within this range led to the use of water with salinities both lower and higher, and tiger shrimp are now grown successfully in salinities from 4–36 ppt (Anon. 1994c). In other areas, a lack of saline water has prompted farms to use water which is almost fresh (Funge-Smith 1997). This is achieved by gradual acclimatisation of larvae to progressively less saline waters (F. Dieberg, pers. comm.; Funge-Smith 1997).

Before the occurrence of white spot virus, postlarvae were usually released into ponds that had not been treated by chemicals prior to the release of the larvae. Nylon nets were commonly used to prevent the entry of fish that could prey on them. Where water was treated, lime, zeolite, dolomite, benzalkonium chloride, or chlorine were used. Manure may also have been added to the pond to encourage the growth of plankton and other micro-organisms to provide food for the postlarvae (NACA 1994a).

However, since the white spot virus, management of ponds and intake water has become more critical. Large intake reservoirs, occupying one-third to one-half of the farm area, have been constructed on many farms to store and treat water before it is used. Treatment commonly involves the use of chlorine and other agents to reduce vectors of the disease (Flegel 1996; Funge-Smith 1997). The use of intake treatment ponds may have economic advantages in areas with water quality problems. NACA (1994a) found that farms in southern Thailand using settling ponds had an average income of 66,110 baht/rai (pond area)/crop compared with 36,169 baht/rai/crop on farms without them.

The amount of water used by each farm is dependent on the quality and quantity of the water available and on the individual management strategies of the farms. It is affected by stocking density, stage of shrimp growth, feeding regime, and food type and quality. The greater the stocking density, the greater the amount of water required to remove the proportionally larger quantity of wastes from the system (Phillips et al. 1993). The percentage of the pond volume exchanged each day was averaged for a sample of intensive farms in the districts of Ranot and Hua Sai according to the stage of growth of the crop (Table 4). As would be expected, the volume and frequency of exchange increased over the rearing period. The study also calculated the volume of water required for ponds of particular sizes with different stocking densities (Table 5).

It should also be noted that the quantity of water used by grow-out farmers has been substantially reduced in recent years following the occurrence of white spot. Farmers consider introduction of new water into the farm to be a potential risk and have adapted management practices to minimise it.

Table 4. Rate and volume of water exchange for intensive shrimp ponds in the districts of Ranot and Hua Sai (NACA 1994a).

Stage of crop	Frequency of water exchange (days)	% of pond volume exchanged
Month 1	12	4
Month 2	6	15
Month 3	4	17
Month 4	3	20

In contrast, shrimp hatcheries use relatively little water. According to Kungvankij et al. (1986), backyard hatcheries can produce 1 million postlarvae per year in 20 m^3

capacity tanks. These hatcheries are sometimes located many kilometres from the sea and use hypersaline water supplied by tanker.

The quality of the water in rearing ponds changes during the growth of the shrimp. It is dependent on water exchange rate and source quality, and such variables as stocking density, feeding rate, and the addition of water treatment chemicals (NACA 1994a). A range of water quality variables is important during rearing; all must be kept within ranges suitable for shrimp. Generally, farmers routinely measure salinity, water transparency (using a Secchi disc) and pH. From these parameters and observations on water colour, an experienced farmer can make adjustments to the system which alter the other parameters.

Table 5. The volume of water required per day for the rearing of shrimp at different densities in ponds of different sizes (NACA 1994a).

Stocking density (shrimp/m^3)	Pond size (rai)	Mean volume of water used (t/day)
25	6	898
50–70	3	273
70–80	2	93
60–100	1	65

Chemicals used for water treatment

Chemicals may be added to pond water during shrimp rearing to improve water quality (pH, turbidity, colour etc.), to check the growth of disease-causing micro-organisms, and to remove fish and other shrimp predators prior to stocking (NACA 1994a). A study of Hua Sai and Ranot Districts (NACA 1994a) gave an indication of the extent to which particular chemicals are used. Its finding are examined here.

Tea seed cake (containing 10% saponin, a natural plant extract) kills fish but does not affect shrimp. It was used by about a third of the surveyed farmers, the frequency and timing of use varying from once per month to once per crop. The two districts showed marked differences in management of the application of this substance. In Ranot it was used by 75% of producers routinely after water exchange. In Hua Sai District there were no farmers who did this (NACA 1994a). Dissolved tea seed cake is recommended for application at 29–40kg/rai (Kongkeo 1989). The study found that the mean application rate for the two districts was a low 16.3kg/rai.

Zeolite was commonly applied by farmers. It was once thought to absorb hydrogen sulphide and ammonia but has been demonstrated to be ineffective for this purpose in saline water (Fegan 1994). Zeolite was used by farmers in Ranot and Hua Sai for reasons such as: to reduce water turbidity (47.6%); to improve the pond substratum (11.1%); to improve water colour (19.3%); to facilitate moulting (3.6%); and to improve water quality (17.9%). The application rate varied from 1–4 times per month. The mean quantity applied was 30.3 kg/rai.

Lime increases the pH of water and sediment. Farmers in Ranot and Hua Sai also used it to reduce turbidity (15%), to disinfect pond water (19%) and to reduce muddy odours (13%) (NACA 1994a). The mean quantity used by these farmers was 47 kg/rai and the frequency of application varied from 1–6 times per month. The recommended quantities for application are 2–4 t/ha (320–640 kg/rai) for pH 3–4 and 0.3–0.5 t/ha (48–80 kg/rai) for pH 6–7 (Tookwinas 1993).

The survey data showed that for all these substances there was a wide range of perceived reasons for use. Additionally, the rates of application varied greatly and there were distinct preferences for the use of different products for particular reasons in the two different districts. For example, 66.7% of farmers in Hua Sai District (of the 32% who used the product) used zeolite to decrease the water turbidity. However, only 28.6% of their counterparts in Ranot District (of the 20% who used the product) considered it effective in decreasing water turbidity. There appears to be a need for education of farmers regarding the effects of these commonly used products and on the appropriate rates and frequencies of application.

Disease treatment and prevention using chemicals

Chemicals, including some antibiotics, are used for disease prevention and treatment in Thailand's shrimp farms. Chemicals include chlorine, iodine, povidine iodine, benzalkonium chloride, bensarzine and formalin. These are mixed with water to kill bacteria and/or viruses in the water and sediment. The antibiotics used most commonly are oxytetracycline and oxolinic acid and these are added to the water or to food (NACA 1994a).

Antibiotics are sold to farmers by salesmen of chemical and drug companies to treat conditions for which there have sometimes been no diagnostic tests to determine the causal organism. In the event of a disease outbreak caused by bacteria, indiscriminate prior use of antibiotics can lead to an ineffective response. A study in the Philippines found multi-resistance in bacteria of the genus *Vibrio*, the organism responsible for fluorescent disease in shrimp (Baticados et al. 1990). The bacteria were resistant to kanamycin, erythromycin, penicillin and streptomycin. According to Fegan (1994), all pathogens present in the shrimp farms examined by the Aquastar Company at that time were resistant to the antibiotics used to treat them.

Oxytetracycline has been a very widely used antibiotic in Thailand, despite some studies which have shown that almost all the bacteria isolated from shrimp and pond water exhibit resistance to it (Fegan 1994). Further, in 1991 the presence of oxytetracycline in shrimp flesh led to the rejection of Thai shrimp by Japan. The problem was partially controlled by the monitoring programs implemented by DOF and the Ministry of Agriculture and Cooperatives, as well as through increased farmer awareness. Farmers need greater knowledge of the circumstances in which use of antibiotics and other chemicals can be beneficial, and to be informed of the potentially detrimental effects of prophylactic antibiotic use. Awareness of correct dosages to achieve particular effects would also be of value to avoid wastage or the use of sub-therapeutic doses.

Nutritional supplements

Substances used as nutritional supplements include biotin, p-aminobenzoic acid, inositol, nicotinic acid, pyridoxine, pantothenic acid, riboflavin, menadione, thiamine, tocopherol, cyanocobalamin, calciferol, ascorbic acid, folic acid and choline (NACA 1994a). Environmental effects are not known, but unlikely to be significant.

Feed

The quantity and quality of feed affects shrimp growth and water quality. Feed types and feeding regimes differ in different areas depending on the availability of various food types. Commercially produced pellet feeds are most frequently used, either alone or previously in conjunction with 'trash fish' (edible species of low commercial value, non-edible species, and juveniles of commercially important species) and clam. The use of such 'wet feed' has recently been reduced, as farmers are concerned about its effects on the pond environment and risk of shrimp diseases. The amount of feed used depends on the density and age of the shrimp, the water quality and the type of feed. Calculations were made of mean feed quantities for farms examined in a survey undertaken by NACA (1994a). These are listed in Table 6.

The amount of food given per rai was averaged from survey data for a single crop in the districts of Hua Sai and Ranot at 2,643 kg/rai and 9,501 kg/rai, respectively. Production levels in both districts were similar but the survival rate in Ranot was 12% lower. In Ranot, the utilisation of feed by shrimp was significantly reduced. The FCR there was 7.2, compared to 1.9 in Hua Sai. The FCR is usually measured as: the total feed input (kg)/total shrimp weight gain (kg) (Tookwinas et al. 1993). To keep wastes in the rearing pond to a minimum, the FCR should be less than 1.5 (NACA 1994a). Higher levels of wastes in the system may have affected mortality rates in Ranot.

Because feed settles directly onto the pond bottom, it can have a significant effect on the sediment quality and thus on the health of the shrimp living there (Boyd 1989). Wickins (1985) estimated that approximately 88% of the nitrogen content in the ponds comes from feed, 13–33% of this from excretion by shrimp.

Table 6. The average feed quantity for shrimp at different stages of production in intensive farms in the districts of Ranot and Hua Sai (NACA 1994a).

Stage of production	Quantity of feed (kg/rai/day)	% of weight of shrimp
Month 1	6.5	30
Month 2	24	60
Month 3	53	100
Month 4	80	80

Sediment

The solid waste products of the shrimp pond ecosystem (feed, excrement, dead plankton etc.) collect on the pond floor as a layer of sediment. The rate of accumulation and the composition of the sediment is a function of the stage of rearing, the farm management procedures, the source of water, the stocking density, and the type and quantity of feed used (NACA 1994a). It contains micro-organisms and chemicals which are in constant and rapid exchange with those in the water column, affecting water quality (Smith 1993, 1996a). As *P. monodon* forage in the top 10 mm of the sediment (Fegan 1994) and sometimes burrow into it during the day, sediment quality directly affects their wellbeing. Inadequately aerated sediments are associated with decreased redox potentials and the release of harmful gases, such as hydrogen sulphide and methane, which can stress shrimp (Boyd 1989). The oxygen demand of the biological processes in sediment account for 75–84% of the total biochemical oxygen demand of an intensive pond (Fast et al. 1988; Hopkins et al. 1991).

The amount of sediment produced by a single pond can be quite large. The average sediment accumulation over the four month rearing period in farms studied by NACA (1994a) was 89.5 m^3/rai/crop. Based on this amount, further calculations determined that the annual total sediment output of all farms in the two studied districts was 2.72 million m^3/yr.

Accumulated sediment is usually removed periodically. This is performed after harvest. It is either mechanically removed using heavy machinery (and dumped onto dykes or designated areas, or into waterways), or pumped or hosed out into settlement ponds.

After sediment removal, the farmers treat the pond bottom with chemicals to eliminate pathogens and to adjust the pH. Lime is widely used, at around 420 kg/rai.

The ponds are left to dry prior to restocking to lower the organic content and theoretically to reduce the levels of potentially harmful bacteria. This may not always be effective. Smith (1993, 1998) examined the bacteriology of different types of farms. There was no significant difference in the levels and types of Vibrionaceae between ponds where the sediment was removed between crops and those where it had not been removed. A similar finding was found for sulfate-reducing bacteria. Drying out ponds between harvests did appear to be an important practice in temporarily reducing bacteria levels. However, even when ponds were allowed to remain dry for four months, after they had been refilled, the numbers of Vibrionaceae in the sediment rapidly returned to the same levels as those prior to drying. Highest levels of vibrios were at times when the feeding rate was highest and the temperature was highest. Smith (1998) concluded that the bacteriology of the sediment is largely driven by input of pelleted feed, ambient temperature and limiting levels of oxygen.

In Thailand, there has been interest in using the sediment as an agricultural fertiliser, but the cost of salt removal and the effluent created in the process have so far discouraged farmers and others from putting it to this use. However, this recycling of pond sediment needs to be looked into further.

Energy requirements and costs

Major items of expenditure for shrimp producers are feeds, postlarvae, chemicals, fuel and electricity. A breakdown of production costs of farms surveyed in Chantaburi Province in 1994 (NACA 1994b) are presented in Table 7 to give some idea of farm costs. The 'other' category of expenditure was not analysed in the study but presumably includes fuel and electricity costs, employment of labour, purchasing of equipment, pond preparation, cleaning and maintenance costs, and loan repayments and servicing.

Many farmers (and in some areas, most farmers) have taken out a loan of some sort to finance their operations. A survey of selected farms in Chantaburi (NACA 1994b) found that 31% of farmers had borrowed money, compared to Ranot and Hua Sai Districts where 73.75% of surveyed farmers had obtained a loan of some sort (NACA 1994a). Interest rates on these loans varied from 13.8–48%. A study of Pak Panang District (Jitsanguan et al. 1993) found that 72% of farmers were paying off loans.

Hirasawa (1992) analysed the costs of production of shrimp from intensive farms in 1987. Although the figures are now dated, they are presented in Table 8 to provide a detailed breakdown of the production costs. Fuel is used for pumping water and running paddle water aerators. Electricity is used for domestic purposes, for aerators and farm buildings. Each pond has at least ten fluorescent lamps for security lighting to discourage poachers (Kongkeo 1995).

Table 7. Items of expenditure and costs of intensive farms in Chantaburi Province. The average culture area of the farms was 23 rai (from NACA 1994b).

Items of expenditure	Cost (baht/rai/crop)	% of total expenditure
Postlarvae	8,426	6.4
Feed	40,907	30.8
Drugs/chemicals	8,246	6.2
Other	75,230	56.6
Total	132,809	

Table 8. Expenditure by intensive shrimp farms in Thailand in 1987. The costs are for one hectare of intensively cultured shrimp. Gross earning and profit are also shown (from Hirasawa 1992).

Item of expenditure		Cost (US$)	% of total expenditure
Seed		2,743.6	13.5
Feeds		6,399.3	31.5
Fertiliser and pesticides		104.7	0.5
Fuel and electricity		2,386.3	11.7
Maintenance and repairs		73.8	0.4
Wages		332.1	1.6
Other		124.2	0.6
Salary		1,872.5	9.2
Rent and interest		5,110.5	25.2
Depreciation		1,159.7	5.7
Total cost	20,306.7		
Gross earning	36,755.6		
Profit	16,448.9		

Impacts of the Environment on Shrimp Aquaculture

As a shrimp farm is part of and interacts with the environment, it is sensitive to changes in the environment outside the farm pond. Ideally, farmers should consider environmental factors when choosing a site for operation; they can affect the success or failure of the venture. Site selection, however, is rarely based on a thorough assessment of features of the natural or human influenced environment and often limited consideration is given to technical, economic, logistic and socio-political factors (Fegan 1994). Environmental factors that impact on sustainability of shrimp farming are reviewed below.

Features of the coastal zone

The availability of a suitable supply of water is one of the most important environmental factors determining site viability for shrimp production. To minimise the costs of pumping water, most farms are located as close as possible to the source of supply. Consequently, many are situated adjacent to the coast, in places elevated slightly higher than the normal high water line. Because of this, farms are vulnerable to seasonal storms and typhoons which cause regular flooding in Thailand's coastal areas (Boromthanarat 1994). For example, flooding in southern Thailand in 1988 resulted in the escape of an estimated 10 million *P. monodon* to the sea.

Water quality

The quality of water in canals and estuaries is affected by activities in the watershed and nearshore waters. The high human population levels, increasing industrialisation of Thailand over the last decade, and agricultural intensification have resulted in significant pollutant levels in many of the country's major rivers. The effects of most of these factors on shrimp farming have not been assessed.

High levels of pesticides contaminating the water supply through agricultural runoff can be lethal to aquaculture animals and lower doses may have sub-lethal toxic effects (Barg 1992). Concern has been expressed regarding the impact of insecticides on aquaculture. Flegal (1992) reported that two of the chemicals used by rice farmers to control crabs in their fields are extremely toxic to *P. monodon* juveniles. These chemicals are the organophosphate methyl-parathion and a fourth generation synthetic pyrethriod, cypermethrin. Methyl-parathion causes 100% mortality of tiger shrimp larvae within 24 hours at concentrations of 15mg/L; cypermethrin, the same mortality rate at only 5 nanograms/L. Flegal (1992) speculated that some of the 'mystery crashes' which occur in shrimp hatcheries may be attributable to exposure to such chemicals. Methyl-parathion and DDT were found in the waters in Rayong Province in 1990 after widespread acute mortalities of shrimp occurred there (Anon. 1994d).

Red tides

Red tides occur in the Gulf of Thailand and their incidence has increased over recent years, possibly as a result of changes in the nutrient budget of coastal waters because of anthropogenic inputs. In areas of southern Thailand they may occur every 3–4 months, whereas only a few years ago they occurred, at most, biannually (S. Boonyaratpalin, pers. comm.). There are at least 10 different phytoplankton species that produce these tides in the Gulf of Thailand (Boonyapiwat 1989) and these affect shrimp in various ways. Blooms of *Oscillatoria* (*Trichodesmium*) *erythrae* and *Nitzschia* irritate the gills of shrimp (Chindanon 1991) and *Noctiluca scintillans* has harmfully high levels of intracellular ammonia (Tanasomwang 1994). Smith (1996b) reported that blooms of cyanobacteria (blue-green algae) could be toxic to *P. monodon*, *Penaeus japonicus* and *Artemia salina*. The exact mechanism is still under investigation.

In the presence of a red tide, shrimp farmers do not take in water, so that their shrimp are not placed at risk. If the tides last for a number of days, a lack of flushing of accumulated wastes from the pond can cause water quality to deteriorate and the likelihood of disease may increase (S. Boonyaratpalin, pers. comm.).

Mangroves

Removal of mangroves can lead to coastal erosion as well as changes in sedimentation patterns and shoreline configuration (Snedaker and Getter 1985). This may affect shrimp farms close to the sea. The presence of mangroves adjacent to shrimp farms helps to protect them from storms and provides a natural ecosystem around the culture area (Tookwinas and Leeruksakiat 1994). The effects of such a natural buffer may also be beneficial in improving source water quality by the uptake of nutrients, and may prevent the spread of disease-causing micro-organisms by maintaining the natural soil micro-fauna.

Poernomo (1990) recommended that large areas of mangroves be left intact to protect shrimp farms and the coastline from the effects of storms, as well as to minimise the effects of shrimp farms on the coastal environment. Depending on the tidal amplitude, a stretch of 50–400 m of mangroves should be left adjacent to the shoreline as a buffer zone, and for the same reason, about 10 m left adjacent to rivers. He emphasised the desirability of vegetated areas for wind-breaks and shade within large farms. He calculated that, depending on the hydrological conditions of the local coastal waters and the level of intensiveness of culture, 10–20 km should be left between farms as a buffer zone.

Substrate

The soil affects the initial cost of pond construction, since soil permeability affects the capacity of the pond to hold water. Soils that are very permeable are least suitable for ponds as water loss from seepage increases the demand for water and therefore pumping costs. There is also a greater chance of salinisation of surrounding land and ground and surface waters.

Seepage occurs through the pond walls and predominantly through the pond floor because of its greater surface area. The seepage rate is greatly determined by the soil type and its particle size. Mittelmark and Landkammer (1990) made calculations of the seepage from aquaculture ponds constructed on different soils (Table 9). Losses were calculated from the daily decrease in pond level and assume that there is no source of water counteracting the seepage.

Early in the development of the shrimp industry in Thailand, estuarine and mangrove areas were recommended as farm sites as they were close to a water source, and to a source of wild postlarvae and juveniles. Rice farms were considered unsuitable because of the large perceived costs of development, lack of tidal exchange, high pumping costs and the possibility of pesticide residues (Fegan 1994). Since then it has been discovered that ex-rice farms are more suitable than mangroves and estuarine marsh. Their higher elevation lowers the potential for self-pollution as waters containing effluent can be drained from the site more easily and ponds can be dried more effectively between cropping cycles.

Acid sulphate soils occur in most mangrove swamps. When present in the soil, iron pyrite (iron sulphide) oxidises on exposure to air, producing sulphuric acid. This causes acidification of the soil, requiring the application of large amounts of lime during shrimp pond preparation (Smith 1993). Oxidation of the pyrites in the pond dykes, followed by heavy rains, can leach sulphuric acid into the ponds.

A number of shrimp health problems are associated with acid sulphate soils. These include soft shell syndrome, red disease and blue shrimp syndrome, all frequently reported in Thailand, the Philippines, Indonesia and Malaysia (Nash et al. 1988; Baticados et al. 1990). In some places in Thailand, the problems associated with these soils have contributed to the occurrence of idle farms (NACA 1994a).

Table 9. The seepage rate from aquaculture ponds constructed from different soil types (Mittelmark and Landkammer 1990).

Soil type	Seepage loss (mm/day)
Sand	25–250
Sandy loam	13–76
Loam	8–20
Clayey loam	2.5–15
Loamy clay	1.25–10
Clay	0.25–5

Harvesting of wild larvae

Most farms in Thailand use hatchery produced postlarvae, so there is no impact associated with the harvest of wild-caught postlarvae, as in some other shrimp producing countries which do not have adequate hatchery production.

Predators

A number of animals consume shrimp from the culture ponds. These include cormorants, herons, terns, otters and fishing cats (Tiensongrusmee 1970).

Impacts of Shrimp Farms on the Environment

Shrimp farms have a number of interactions with the natural environment which vary considerably depending on such factors as the farm location, the number of farms, and the type and management of the farm operation. Some of these environmental interactions are considered below.

Pond effluent water

Water is periodically exchanged in most shrimp ponds to provide clean water and remove accumulated waste materials. The effluent is discharged into natural water bodies, sometimes with limited treatment. Water during farming operations is of reasonable quality, but poorer quality effluent may be discharged during harvest and following harvest when ponds are cleaned and the sediment removed. Because of the properties of the effluent, changes in the chemistry and community ecology of the receiving waters may occur where there is limited water exchange in receiving waters. Where there is high effluent discharge and limited water exchange, the following changes in receiving waters may occur:

1. effluent water that is low in oxygen and has a high biochemical oxygen demand (BOD) will lower the oxygen level of the receiving waters;
2. hypernutrification (an increase in dissolved nutrients) can lead to an increase in primary productivity where phytoplankton and other marine plants are limited in their growth by nutrients (eutrophication); and
3. suspended solids in the effluent cause increased sedimentation rates when they settle, leading to siltation of canals and possibly an alteration in the structure of the benthic community.

Robertson and Phillips (1995) compiled data on nutrients, suspended solids, chlorophyll *a* and bacterial cell density in effluent water from intensively managed shrimp ponds and presented them with data from pristine mangrove waterways for comparison. These data are presented in Table 10 and they show elevated levels of ammonia, chlorophyll *a* and bacteria in intensive shrimp pond effluent.

Table 10. Nutrient levels, particle concentrations, and bacterial cell densities and production in effluent water from intensively managed shrimp farms, together with those of pristine mangrove waterways (from Robertson and Phillips 1995).

Variable	Intensive shrimp pond effluent	Pristine mangrove waterways
Salinity (%)	10–35	0–37
Ammonia—NH_3 (μM)	1.97–73.15	0.10–1.42
Nitrate—NO_3 (μM)	0.05–1.54	0–11.75
Phosphate—PO_4 (μM)	0.53–4.21	0–5.26
Total suspended solids (mg/L)	119–225	67–3,312
Chlorophyll *a* (μg/L)	20–250	0.2–5.07
Bacterial number (cells/ml)	$8.8–25.7 \times 10^{6}$[a]	$0.85–4.70 \times 10^{6}$
Bacterial production (μg/L/d)	39–87[a]	0–18

[a]Based on semi-intensive ponds (Moriarty 1986)

In Thailand, the quality of effluent water from 15 intensive culture ponds was monitored by Chaiyukum et al. (1992). The measured water quality parameters were: BOD, 4.0–10.2 mg/L; phosphorus, 0.0001–2.02 mg/L; and nitrogen, 0.03–1.2 mg/L. NACA (1994a) noted that these levels compared favourably to the local sewerage outputs (with a BOD of 300 mg/L) and discharges from a local fish processing plant (BOD 10,000–18,000 mg/L). Calculations for the districts of Ranot and Hua Sai undertaken by NACA (1994a) established that the total daily discharge of effluent water was approximately 93,747 m^3/day, 65% of this into the canals, 29% into the sea and the remainder elsewhere. Further calculations estimated that this discharge meant a load to the coastal waters of suspended solids of 4.5 t/day, phosphate 48 kg/day, ammonia 13 kg/day, and a BOD of 180 kg/day (NACA 1994a). In addition, there is a daily production of 1,500 m^3 of sludge (Briggs 1993a,b; Briggs and Funge-Smith 1993), 22 t of phytoplankton and 122 t of total organic matter (Lin et al. 1991). Whilst much of this material is readily diluted in the coastal waters, particularly during the rainy season, some deterioration of inshore water quality has been noted at times.

Elsewhere, and notably in the Upper Gulf of Thailand, the nutrient loads from coastal shrimp farms have been shown to be insignificant when compared to other sources of the coastal nutrient loads, particularly nitrogen and phosphorus from agricultural and domestic sources (Pollution Control Department 1997).

Treatment of effluent water

On smaller farms, most effluent water is discharged without treatment. Where water is treated, settlement ponds are the most commonly used method. These are effective at decreasing the levels of phosphorus, dissolved nitrogen and suspended solids, but BOD can increase because of the high nutrient levels in the ponds and because of phytoplankton blooms (Briggs and Funge-Smith 1994). On larger farms, greater than 50 rai, Thai Government regulations that came into effect in 1991 stipulate that effluent must be treated via settlement ponds of a size equivalent to or larger than 10% of the total farm area.

In one study, the required size of settlement ponds was calculated from measurements of the settling velocity of particulate matter in the effluent (Smith 1995). A settlement pond of 0.75 ha for an effluent discharge of 1 m^3/s was found to be suitable. The study showed that more than 90% of the diatomaceous silica (in diatom shells) that accumulated in ponds was derived from the weathering of clay from pond walls. Also, the effluent contained a high level of inorganic material that was eroded from the soil in the ponds. Consequently, much can be done to reduce sediment loadings by improving soil conservation on the farm, and particularly through the use of liners and other methods to keep pond walls intact.

Biological methods of water treatment have been investigated in Thailand and elsewhere. The green mussel *Perna viridis* has been trialled (DOF 1992) with some success at reducing BOD, organic solids and phytoplankton. This mussel, however, is sensitive to salinity fluctuations and its production of faeces and pseudo-faeces may add to sediment loads. The seaweed *Gracilaria* has been grown in conjunction with green mussels and shown to reduce soluble nutrients. Unfortunately it is also sensitive to salinity fluctuations, and in turbid and eutrophic pond effluent suffers from light limitation, as well as smothering by sediment and epiphytic microbial growth. Currently under investigation at the Petchaburi Coastal Aquaculture Centre is the use of a native seagrass. Various groups of bacteria are under examination to assess their usefulness in accelerating the breakdown of pond wastes (Keawchum 1993).

Sediment disposal

Sediment from ponds is usually removed at the completion of the production cycle. NACA (1994a) found that 36% of surveyed farms dumped sediment along the pond dykes, 36% in designated sediment disposal areas, and the other farms disposed of it elsewhere. Discharge of pond sediment into water bodies has the potential to affect them in a similar way to effluent water, but there is a high degree of awareness among farmers of this problem and most places of disposal are now away from waterways. Because it is high in salinity, it is not colonised readily by most plants until the rain has had chance to wash away some of the salt, which usually takes around two years. Some farmers recycle the sediment after two years to repair dykes and pond walls.

Self-pollution

The discharge of effluent water into the same canals used for water supply means that farms may pollute their own and their neighbour's supply, contributing to water quality deterioration. In recognition of the problem, DOF and the Irrigation Departments have embarked on a number of engineering works aimed at separating effluent drains from intakes. In Surat Thani Province, some farmers have attempted to address the problem of self-pollution with a flag system that warns neighbours when effluent discharge is in progress (MacIntosh and Phillips 1992). In other areas, farmers have stipulated times for effluent release coordinated with the tides. DOF is trying to further promote such coordination between farms. In the south, the Aquastar Company constructed large seawater intakes, 200 m out to sea, to service its contracted farms. These intakes are able to access cleaner water than can be obtained closer to shore.

Spread of shrimp disease

Disease-causing micro-organisms discharged in effluent water may be spread to nearby farms or to organisms in the natural environment. Smith (1993, 1998) has shown that the organisms of the family Vibrionaceae are significantly higher in mangrove sediments close to farms compared to those at a distance. This finding suggests that farms should maximise the distance between their intake point and their effluent canal or their neighbours. However, in general the interactions between farm location, density and shrimp disease occurrence are poorly understood, and more research is needed to develop guidelines on this subject.

Salinisation of land and water

In some places, saline effluent water and seepage from ponds have contributed to year-round salinisation of canals that were previously saline only in the driest periods of the year. Where this occurs, traditional agriculture and sometimes drinking water have been affected. Although a number of other factors have contributed to salinisation of land and water in Thailand, where it occurs in shrimp farming areas, these farms tend to be the obvious focus for blame. Conflicts between non-shrimp farming residents and shrimp farmers in some coastal areas of Thailand were common, although these problems are fairly rare today. Of more recent concern are the effects of inland shrimp farming on agricultural areas, although there is a lack of scientific study on this particular problem (Lin 1998).

In Ranot District in southern Thailand, the watertable dropped from 3 m to 7 m between 1989 and 1991. This was attributed not to shrimp farming, but to deforestation of catchment areas resulting in decreased percolation of water into the soil, and decreasing rainfall over the period (NACA 1994a). This shows the complexity of judging environmental change and the need to consider the potential impacts of shrimp culture within the context of all activities in the coastal area of the watershed.

Land subsidence

Coastal land subsidence has been reported in the Philippines (Primavera 1989) and in Taiwan (Chiang and Lee 1986) as a result of the extraction of fresh water from underground aquifers for shrimp farming. However, there are no recorded incidences of land subsidence in Thailand which can be directly attributed to shrimp farming.

Impact on fisheries

Populations of many marine organisms are subject to natural fluctuations and are affected by a diverse range of human activities. It is therefore difficult to identify or quantify the effects of shrimp farming on Thailand's fisheries.

The fish catch in the major rivers, canals and swamps is declining because of increased fishing pressures, ineffective enforcement of regulations governing fisheries habitats, and the environment—through environmental degradation, loss of floodplain area and destruction of fish habitats (DOF 1994). Demersal fisheries in the Gulf of Thailand and the Andaman Sea are declining also, as a result of over-exploitation. Pelagic fisheries have increased production over the last 20 years due to improved capture methods, but at present most are fully exploited and are beginning to show signs of stock depletion (DOF 1994).

It is clear that there is a need for research on the interactions between fisheries and shrimp aquaculture, and into developing suitable alternative feed components that will reduce the requirement for fish or fish products in aquacultural feeds.

Changes in coastal configuration

In some areas of Thailand, some shrimp farm development has changed the coastal configuration, a consequence of the removal of mangrove forest and the subsequent exposure of intertidal zones to the erosive potential of wind and wave action. Additionally, water intake installations on jetties alter the natural flow of sea currents causing some changes in local sedimentation and erosion (Boromthanarat 1994).

Changes in habitat

Most literature considering the loss of habitat for shrimp farm development deals exclusively with mangrove loss. However, some wetlands have also been lost to shrimp development. Piamsomboon (1993) stated that 5.9% of shrimp farms were on land described as previously 'unproductive', a proportion of which was probably wetlands.

Mangrove forests are known to be important to coastal ecology, providing nursery areas for species of shrimp, crab and fish, many of which are commercially important. Mangrove forest in Thailand contains at least 68 species of plants, 72 species of fish, 54 species of crab, 20 varieties of mollusc, 88 bird species (both migratory and residential), 35 species of mammals and 25 species of reptiles (OECF 1992).

Some mangrove forests were cleared for shrimp farming during the early expansion of extensive farming, but little is known of the original state of this forest, and it is clear that shrimp farming is only one of the contributors to the loss of mangroves in Thailand. The total mangrove area in 1961 was 2,299,375 rai; by 1989 it was reduced to 1,128,497 rai, a rate of destruction of 1.82% per year. Most of this occurred between 1980 and 1986 when extensive shrimp farming expanded. Apart from shrimp farming, reasons for deforestation included salt farming, mining and community expansion (NACA 1994a). Exact figures for the area cleared specifically for shrimp farming are not presented here as there are discrepancies between those published by different individuals, but common estimates suggest that shrimp farming contributed from 14–20% of the loss of mangrove forests in Thailand (P. Menasveta, pers. comm.). Recent government efforts and an increasing realisation among farmers that mangroves are poor sites for intensive shrimp farming have led to a significant reduction in the use of mangroves for shrimp culture.

A government resolution aimed at protecting the mangrove forests was passed in December 1983 (Katesombun 1992). It divided the mangroves into three areas:

1. Economic Area A. Only charcoal concessions are allowed; factories, shrimp farms and village communities are prohibited from using the area.
2. Economic Area B. These are areas with either no mangrove forest left, or degraded mangrove forest. Villagers are entitled to use and live in the area and factories and shrimp farms are allowed.
3. Conservation Area. Villagers cannot live in the area. Charcoal concessions, factories and shrimp farms are prohibited.

Effects on the genetics of wild shrimp populations

Shrimp aquaculture in Thailand uses species found in the local waters so there is no risk of escape of exotic species into the natural environment. However, an alteration in the gene pool of naturally occurring shrimp may occur with interbreeding of escaped cultured stock and wild populations. The artificial rearing conditions of an aquaculture pond may select for the survival of very different traits than those selected for in wild animals. In addition, the wild species provide a potential source of genetic material for the future domestication and genetic selection program being planned in Thailand. There is a need to study the gene pools of wild stocks in order to ascertain their variability, distribution and abundance.

Research Organisations, Education and Training, and Export of Shrimp Farming Knowledge

Education and training in shrimp aquaculture in Thailand

Education and training of shrimp farmers are factors which greatly affect their performance as farm managers. Research has shown that the formal education of many farmers is quite brief. The Office of Agricultural Economics (1991) discovered that 85.2% of all shrimp farmers had been formally educated to a level of less than Grade 5 and around 80% of these people operated intensive farms. This generally low standard of formal education was identified by NACA (1994a) as a potential impediment to a sustainable shrimp farming industry. The techniques, technology and management strategies necessary to reduce environmental pollution whilst maintaining high production are often complex and people with this level of education may have problems understanding them. According to T. Jitsanguan (pers. comm.), the greater a farmer's education, the greater his or her ability to keep a farm operating over time. Jitsanguan observed that it is usually the less educated farmers who fail first when an area becomes environmentally degraded. Profitability of farms has also been positively correlated to a higher education level (Jitsanguan et al. 1993).

Generally speaking, most shrimp farmers have not been involved in the industry for very long and are relatively inexperienced. Of the farmers surveyed by NACA (1994a), only 1% stated that their previous occupation was shrimp farming. 50% had been rice farmers, 14% had been fishermen and the remainder came from various other occupations or had been unemployed. Most had only 2–3 years shrimp farming experience at the time of the survey. A similar proportion of previous occupations was recorded by Jitsanguan et al. (1993) in Pak Panang District. There, 95% of farmers had been farming for four years or less. This structure of experience reflects the relatively recent evolution of the industry in most areas.

In addition to inexperience, there is apparently a lack of specialist consultation to acquire information pertaining to production. Of a group of farmers asked their sources of technical information (OEPP 1994), 60% said they consulted friends (presumably other shrimp farmers), 23% consulted their parents, 4% consulted other relatives, 4% consulted shrimp farmers from elsewhere, and 2% other sources. 8% of the surveyed farmers said they used their own ideas. A survey by Jisanguan et al. (1993) found that 54.3% of farmers had no training in shrimp farming at all. Of those that had training, almost 70% came from the private sector and only 11.4% obtained training from DOF. The remainder received training from other, non-specified government agencies.

A recent workshop on shrimp health management identified a lack of available information or lack of dissemination of accurate or correct information to farmers as a great impediment to sustainable farming (Turnbull et al. 1994). The workshop concluded that improvement in this area required government funding and expressed concern that reliance on commercial companies to perform the role of education may result in the dissemination of information with a commercial bias.

It is possible that education and training or experience can provide farmers with only a certain knowledge to maintain intensive production indefinitely where the carrying capacity of the environment is exceeded. This suggestion has been made by Jisanguan et al. (1993) who studied the relationship between the level of experience of farmers and the profitability of farm operation. They expected that the longer a farmer had been operating, the more skills he or she would have acquired and the greater the farm's profitability would be. However, they found the opposite situation—profitability decreased with experience. This aspect deserves more analysis but shows the importance of some form of intervention to limit the number of farms, even where there are well-educated farmers.

It would appear that research is needed to find the most appropriate means of providing extension of research results to the industry.

Thailand's role in the export of knowledge and technology

As Thailand's success in producing shrimp for export is well known in the Asian region, it is looked to by other countries seeking information on the development of such an industry. For example, Charoen Pokphand, a Thai company, began operations in shrimp farming in 1986 and is now the world's largest shrimp farming company. It produces feed and contracts farmers to produce shrimp under its guidance. It is the largest shrimp feed producer in Indonesia (Lohawanthanakal 1993) and has expanded into China, Vietnam and India (Lohawanthanakal 1993). Whilst there is undoubtedly a considerable store of knowledge on shrimp aquaculture in Thailand, those involved in the transmission of information from Thailand to other countries need to maintain the quality of the knowledge they transmit. Countries can learn also from both the successes and failures of the Thai shrimp industry.

Shrimp aquaculture research organisations in Thailand

Much of the research into shrimp farming in Thailand is carried out by DOF and within the Thai university system. Within DOF, there are a number of sub-departments that are responsible for particular areas of aquaculture. There are five regional Coastal Research Centres where fisheries and aquaculture research are carried out. In nearly all coastal provinces there are Fisheries Stations (B. Tiensongrusmee, pers. comm.). The Samut Sakhon Coastal Aquaculture Station is involved in developing and improving shrimp culture and hatchery techniques, and in environmental monitoring of inland and coastal waters. It also produces postlarvae for sale to local farmers. The Petchaburi Coastal Aquaculture Experimental Station is involved in research aimed at developing shrimp culture techniques that will assist in the recovery of abandoned shrimp ponds in the area. Closed culture techniques and treatment of effluent water using seagrass are currently under investigation. The centre produces *Artemia* for shrimp feed, using shrimp factory wastes and the bacterial waste from a local monosodium glutamate factory for feed.

The National Institute of Coastal Aquaculture (NICA), situated on the coast at Songkhla in southern Thailand, is one of the major research organisations involved with shrimp farming. It has five departments, each dealing with different aspects of shrimp culture (as well as finfish culture). They are currently involved in: examining water quality in shrimp ponds and defining parameters which are necessary for shrimp health; diagnosing and developing treatment for, and prophylactic measures to prevent, particular diseases; and examining and improving various diets for shrimp. They are also working on the development of disease resistant broodstock. NICA passes on information from its research to other DOF departments and to private companies. It relies on these to disseminate its research findings to farmers. It organises occasional seminars for farmers to deal with particular problems. The Aquatic Animal Health Research Institute on the campus at Kasetsart University also undertakes research and runs popular national and regional training courses on shrimp aquaculture.

The National Statistics Office and DOF have conducted marine fisheries censuses which included examinations of shrimp aquaculture in 1967 and 1985. A third census was planned for 1995. This comprehensive survey was to assess the number of shrimp aquaculture establishments, the area under culture, the tenure of the farm, the number of employees, the source of seed stock, and perform a socioeconomic assessment of the farmers, farm employees and their dependents (Nakalak 1994).

Universities also carry out some research, and there are a small number of internationally financed research projects. Of particular note is a series of research projects coordinated by the Institute of Aquaculture of the University of Stirling, Scotland. These have been funded largely through the British Overseas Development

Administration. Their work has involved disease research, research into aspects of sediment and water quality, and modelling of the nutrient budgets of farms.

Thai Government Policy and Shrimp Farming

Legislative administration of the coastal area in Thailand

Table 11 summarises the main legislation applicable to the coastal zone in Thailand, in terms of national policy and planning, land-use control, environmental quality, and exploitation and conservation of natural resources. Government agencies responsible for coastal area administration and coastal resources management may be placed in three categories (MIDAS 1995): policy agencies, planning agencies and implementing agencies.

Table 11. Legislative administration of the coastal area in Thailand. (Note: Some Acts occur in the table more than once because they influence more than one area of activity.)

<table>
<tr><th>Legislation</th><th>From exclusive economic zone to territorial sea (188 sea miles)</th><th>From territorial sea to shoreline (12 sea miles)</th><th>Land</th></tr>
<tr><td>National policy and planning</td><td></td><td colspan="2">National Economic and Social Development Act, 1978
National Environment Act, 1992
Tourism Authority of Thailand Act, 1979
Agriculture Economic Act, 1979</td></tr>
<tr><td>Land use control</td><td></td><td></td><td>Land Code of Thailand, 1954
Town and Country Planning Act, 1975
Building Control Act, 1979
Agricultural Land Consolidation Act, 1974
Agricultural Reform Act, 1992
Land Development Act, 1983</td></tr>
<tr><td rowspan="3">Environmental quality</td><td></td><td></td><td>Building Control Act, 1992</td></tr>
<tr><td></td><td colspan="2">Navigation in Thai Waters Act, 1913
Enhancement and Conservation of Environmental Quality Act, 1992</td></tr>
<tr><td colspan="2">Fisheries Act, 1947</td><td></td></tr>
<tr><td>Natural resources</td><td></td><td></td><td>Forest Act, 1941</td></tr>
</table>

Table 11. (cont'd) Legislative administration of the coastal area in Thailand. (Note: Some Acts occur in the table more than once because they influence more than one area of activity.)

<table>
<tr><th>Legislation</th><th>From exclusive economic zone to territorial sea (188 sea miles)</th><th>From territorial sea to shoreline (12 sea miles)</th><th>Land</th></tr>
<tr><td rowspan="4">Natural resources (cont'd)</td><td></td><td></td><td>National Forest Reserves Act, 1964</td></tr>
<tr><td></td><td></td><td>Wild Animals Preservation and Reserves Act, 1960</td></tr>
<tr><td colspan="2">Mineral Act, 1976
Petroleum Act, 1971</td><td></td></tr>
<tr><td colspan="2">Fisheries Act, 1947</td><td></td></tr>
<tr><td rowspan="5">Conservation of natural areas</td><td></td><td></td><td>Wild Animal Preservation and Reserve Act, 1960</td></tr>
<tr><td></td><td></td><td>National Forest Reserves Act, 1964</td></tr>
<tr><td></td><td colspan="2">Enhancement and Conservation of Environmental Quality Act, 1992</td></tr>
<tr><td></td><td colspan="2">National Park Act, 1961</td></tr>
<tr><td colspan="3">Fisheries Act, 1947</td></tr>
</table>

Policy

The two agencies with responsibility for coastal area policy formulation and coordination are:

- the Office of the National Economic and Social Development Board (NESDB) in the Office of the Prime Minister, which is responsible for overall planning as well as national economic and social development policy formulation; and
- the Office of Environmental Policy and Planning (OEPP) in the Ministry of Science Technology and Environment, which formulates and coordinates detailed national resource policies and plans.

The National Committees that develop policy and give advice to planning and implementing agencies are as follows:

- National Environment Board. This takes care of the whole environment—setting national policy to protect the environment and natural resources management.
- Land Development Committee. For land classification, this tries to find ways to improve land-use planning and development.
- Central Sub-committee on the Development of Coastal Areas. This reviews and improves other projects that involve land development.
- Provincial Sub-committee on Coastal Area Classification and Development. This considers projects that involve land classification, provides land information for

agriculture, selects coastal land projects, carries out baseline studies and supports research on coastal land development.

- National Mangrove Resources Committee. This committee of the National Research Council gives advice on planning and research methods and reviews problems with mangroves.

Although NESDB has responsibility for policy, OEPP has responsibility for preparing and coordinating policy on national resource planning in the following areas:

- preparation of policy and planning for conservation of environmental quality;
- cooperation for environmental management;
- monitoring and reporting problems with natural resources;
- modification of projects that damage environmental quality;
- Initiation and giving advice for international cooperation;
- recommendations for policy and cooperation for environmental funds; and
- resolution of environmental problems.

Planning

Agencies that have planning responsibilities in coastal areas include:

- Tourism Authority of Thailand;
- Town and Country Planning Department;
- National Resources and Environment Office;
- Office of the National Research Council of Thailand;
- Department of Land Development; and
- Office of Environmental Policy and Planning.

Implementation

The main agencies implementing policies and plans are:

- DOF, Ministry of Agriculture and Cooperatives;
- Royal Forest Department;
- Office of Agricultural Economics;
- Department of Land Development;
- Pollution Control Department;
- Department of Local Administration, Ministry of Interior;
- Harbours Department and Department of Highways, Ministry of Transport and Communications; and
- Royal Irrigation Department, Ministry of Agriculture and Cooperatives.

Policies and regulations

DOF (1994) summarised the Thai Government policies regarding shrimp production. The government's official goals are:

- the total area under culture to 76,000 ha;

- conversion of traditional and semi-intensive farms to intensive culture;
- enforcement of the treatment of effluent water prior to release into receiving waters;
- implementation of seawater irrigation systems in all major areas of shrimp culture to increase the quantity of water available to shrimp farms;
- strengthening of hatchery and farm registration to ensure shrimp product quality;
- establishment of a product investigation laboratory in 1994 in every coastal province to investigate antibiotic residues before harvesting and before sale to cold-storage operators;
- research on marine shrimp spawner maturation in captivity to eventually minimise the reliance on wild spawners;
- research on shrimp genetics to develop fast-growing, disease-resistant strains; and
- investigation of the potential of alternative species for pond culture.

The specific regulations formulated by DOF (the Government Department which deals with shrimp aquaculture) to address the environmental problems of shrimp farming are:

1. shrimp farms and hatcheries must be registered;
2. the BOD of effluent water must be below 10 mg/L and the Secchi disc transparency greater than 60 cm;
3. prior to discharge into canals etc., effluent water from farms greater than 50 rai must be treated in settling ponds of not less than 10% of the rearing pond area; and
4. release of salt water into freshwater bodies and the discharge of silt and sediment into public water bodies or onto public land are forbidden.

These listed policies and regulations appear straightforward enough, and to an extent have the potential to lessen the environmental impacts of shrimp farming, and therefore to reduce some of the problems faced by the industry.

DOF has also encouraged farmers to join cooperatives where members must agree to adhere to effluent discharge practices that are not detrimental to others. According to S. Tookwinas (unpublished observation), this strategy is reasonably effective. In some groups the fine for breaking the cooperative's rules is as high as 2,000 baht (A$110), a much greater incentive to obey rules than the official fine.

To overcome difficulties in planning and regulation, there is an urgent need for coordinated approaches to deal specifically with issues of the shrimp industry and to formulate policies based on an assessment of all industry, environmental, social and economic issues. Such an approach could also help in determining effective methods of implementing policies within the existing constraints of the government system.

Sustainability, Sustainable Development and Sustainable Shrimp Farming

From the preceding review of shrimp aquaculture in Thailand, it is apparent that there are a number of key researchable constraints to the development of a sustainable shrimp farming industry.

The ultimate goal of economic development should be the progressive improvement of human welfare. Traditional economic approaches have come under increasing criticism over the past decade because they are not achieving this. In poorer countries in particular, traditional economic development approaches have: contributed to widening divisions between the rich and the poorer people; fitted poorly within the political and social infrastructures; and created environmental problems (Marsden 1990). Broad-scale environmental degradation has resulted from ill-planned economic ventures fostering the widespread belief, especially in developing countries, that some degradation of the environment is a necessary and justifiable cost of economic growth (Dixon et al. 1988).

Although much had previously been written regarding these issues, the Brundtland Report (World Commission on Environmental Development 1987) was one of the first documents to fully consider and draw widespread attention to them. The Commission concluded that the extent of the world's problems indicated the need for the development of policies which considered future people as well as those in the present, and safeguarded the environment.

Sustainable development

Since the Brundtland Report, the concept of sustainability has been much discussed and the definition expanded. 'Sustainability' is considered to be the long-term and difficult to achieve goal of reaching an environmentally, socially and economically sustainable state. The processes by which this goal is approached are encompassed by the term 'sustainable development' (Dovers and Handmer 1994). These processes include the formulation of a social and economic system which ensures that there is a real rise in the income of the populace overall, improved health and education, and a general state of social wellbeing (Barde and Pearce 1991). This system of development must be technically appropriate to particular situations, be socially acceptable, place importance on the conservation of land, water, plant and animal genetic resources, and be environmentally non-degrading (FAO 1991). The natural environment, the resource base on which all economic development ultimately depends, either directly or indirectly, is naturally given considerable attention in all discussions of sustainable development. According to Jacobs (1991), "...the environment should be protected in such a condition and to such a degree that environmental capacities (the ability of the environment to perform its various functions) are maintained over time: at least at levels sufficient to avoid future catastrophe, and at most at levels which give future generations the opportunity to enjoy an equal measure of environmental consumption".

The World Conservation Strategy (cited by Brooks 1990) provided an evaluation of the needs of the policies and practices geared towards reaching a sustainable state. These effectively summarised the major issues identified by researchers dealing with the subject. According to this document, for development to be sustainable, strategies must be devised to address and respond to five broad requirements:

- integration of environmental conservation and development;
- satisfaction of basic human needs;
- achievement of equity and social justice;
- provision for social self-determination and cultural diversity; and
- maintenance of ecological integrity.

Achieving sustainable development

Various authors suggest that strategic environmental assessment can contribute to achieving sustainable development. This is a systematic and comprehensive process of evaluating environmental assets, and the environmental impacts of policies, plans or programs and their alternatives. It includes the preparation of reports on the findings of the evaluations, and using the findings in publicly accountable decision making. Factors to be considered in the process are (Therivel et al. 1992):

- cumulative impacts of developments—synergistic impacts where the impacts of several projects may exceed the sum of their parts;
- threshold/saturation impacts where the environment may be resilient up to a certain level but beyond that becomes rapidly degraded;
- induced and indirect impacts where one development can stimulate secondary developments and infrastructure; and
- time -crowded or space-crowded impacts where the environment does not have the time or space to recover from one impact before it is subjected to the next one.

The evaluation of social impacts needs to be performed. This process involves measuring the costs and benefits to society of particular projects and activities. Objectively balancing the concerns of all community groups can be difficult, particularly as those with greater influence, wealth and education are usually most involved in the assessment and decision-making processes.

All these issues must be considered within the context of economic factors. Not only is it necessary to assess the appropriateness of a project in the present; future costs, market prices and product demand need to be determined so that planned projects will fit into and succeed within future economic scenarios.

Strategic environmental assessments of the shrimp industry could be a useful tool in guiding future development strategies.

Sustainable shrimp culture development

The results of research and the recommendations that flow from research can be key factors contributing towards sustainability of the industry. The development and adoption of sustainable practices will require the cooperation of government and farmers, and identification of the priority areas of research.

In order to identify the priority areas for research, the stakeholders need to agree on the factors involved in sustainability. The inference from most papers is that 'sustainability' encompasses only the environmental factors within and outside farms that affect the long-term productivity of the farm unit. With the exception of a few papers, socio-cultural and environmental asset values are not discussed. In addressing sustainability of shrimp farming, it is important to go beyond the search for solutions to improve the production within the pond. They must deliberate upon and evaluate all issues affecting the industry and then identify research and formulate policies accordingly.

Some Key Researchable Constraints

The widespread recognition of the need to develop sustainable shrimp farming practices has been prompted by the failure of farms in various countries and in areas of Thailand. Much research has been directed toward on-farm management issues and to solving production problems, mainly concentrating on water quality, and disease diagnosis and control. There is, however, a need to broaden research to encompass the wider social, economic and environmental issues beyond the immediate farm. Based on this review, Table 12 lists the major impediments to a sustainable industry in Thailand. These were identified through an extensive literature survey and by interviewing a variety of researchers and officials from both private and Government organisations in Thailand. Measures to tackle some of these impediments have been instituted and research into others has been performed or is currently being done. Table 12 lists these measures or research projects, naming the persons or organisations involved.

Some of the impediments to the development of a sustainable industry listed in Table 12 have the potential to be solved by research. Others, including all those identified in the regulation, policy and research sections, need to be addressed by changes in policy administration and management. These impediments have been presented because their resolution is integral to the success of the implementation of research findings.

Key researchable issues into sustainable shrimp farming

Table 12 allows the impediments to sustainable shrimp aquaculture to be identified and compared to the activities, processes and research that are currently under way to address these problems. Impediments that can be reduced by research are discussed here and summarised in Table 13.

Water quality

One of the most important factors in the successful production of shrimp is water quality. For this reason, this area has been the focus of a large proportion of research projects. Even so, there are still gaps in the understanding of the processes which occur within pond water and sediment and their relationships to shrimp health. Ongoing research by all major research institutions in Thailand is attempting to address these gaps. One area that continues to be neglected, however, is the relationship between the quality of the sediment in ponds, the management practices which create the sediment and the water quality, and shrimp health.

Table 12. Impediments to the development of a sustainable shrimp farming industry in Thailand and the research into these impediments, or the measures taken to address them.

Category	Impediments to a sustainable shrimp aquaculture industry	Current or recent research in Thailand, or remediation measure[a]
Regulation	• Need to improve effectiveness of enforcement of government regulations, including zoning and limits to shrimp farm production area. • Absence of a government department to deal specifically with the unique problems of the shrimp industry. • The requirement for larger farms to have settlement ponds of at least 10% of their area has not been arrived at through detailed studies to determine whether this area is sufficient to improve water quality.	• This will be pursued in a current study by the Network of Aquaculture Centres in Asia–Pacific (NACA) and the Pollution Control Department.
Policy	• Need to base limit on the expansion of the shrimp industry on a scientific assessment of environmental carrying capacity.	
Research	• Need to improve exchange of information and ideas between researchers and workers in the government, academic and private sectors. • Need to improve effectiveness of transmission of current research findings to policy makers, planners and farmers. • Industry research is primarily directed toward pond processes with the aim of increasing or maintaining production. Other aspects of the industry (e.g. environmental, social, marketing, improved engineering etc.) require more attention.	• The Thai Department of Fisheries (DOF) and private companies produce some literature for farmers and organise seminars. These efforts should be expanded.
Water quality	• Pollution of water supply with industrial effluent, agricultural chemicals etc.	• Charoen Pokphand Group (CP) and others are studying the safe levels of particular heavy metals and pesticides and attempting to develop antidotes for pesticide-affected shrimp. NACA and the Pollution Control Department are testing waters in shrimp farming areas to identify and quantify pollutants.

Table 12. (cont'd) Impediments to the development of a sustainable shrimp farming industry in Thailand and the research into these impediments, or the measures taken to address them.

Category	Impediments to a sustainable shrimp aquaculture industry	Current or recent research in Thailand, or remediation measure[a]
Water quality (cont'd)	• Self-pollution of water supplies from the discharge of effluent into receiving waters. (High farm densities per km of coastline may exceed the capacity of the environment to assimilate farm discharges in some areas.)	• Ongoing studies by DOF. Current study by NACA and the Pollution Control Authority.
	• Gaps in knowledge regarding farm management practices and water quality and lack of a clear understanding of the relationship between sediment quality and water quality.	• Studies have been carried out and are also currently under way by researchers at CP, the National Institute of Coastal Aquaculture–Department of Fisheries (NICA), Institute of Aquaculture (University of Stirling, United Kingdom[b]), Tinsulanonda Songkhla Fisheries College, Kasetsart University Faculty of Fisheries, NACA and the Pollution Control Department, Aquastar, MRAG[c] and Mahidol University.
	• Need for improvements in on-farm water treatment and recycling which have the potential to decrease environmental impacts of farms and to help reduce the impacts of poor quality water from supply sources.	• DOF and CP are researching the development of a closed system where water is recycled within the farm and water is only added to compensate for evaporative losses and to control salinity.
	• Inadequate knowledge of the role of various micro-organisms in the breakdown of metabolic wastes, unutilised food and chemicals added during the rearing process, and of environmental manipulation techniques which will optimise their growth and performance.	• Currently under study by CP and S. Keawchum, Asian Institute of Technology.
	• Algal blooms in some locations with unknown impacts on shrimp production.	• DOF recommends the use of reservoir ponds so that water can be stored and used for water exchange during red tides.
Effluent	• Release of effluent from ponds can lead to changes in the ecology of receiving waters and reduced carrying capacity.	• Regulation by the DOF requiring farms greater than 50 rai to have treatment ponds.

Table 12. (cont'd) Impediments to the development of a sustainable shrimp farming industry in Thailand and the research into these impediments, or the measures taken to address them.

Category	Impediments to a sustainable shrimp aquaculture industry	Current or recent research in Thailand, or remediation measure[a]
Effluent (cont'd)	• Absence of a range of effective organisms for biological treatment and improvement of effluent water quality.	• Studied by CP and DOF. Also a study by Dr Turnbull (Inst. of Aquaculture) into commercially produced bacterial and enzyme water treatments.
	• The current effluent standards for coastal aquaculture have not been based on an assessment of the impacts of effluent on receiving waters.	• Current project to determine effluent standards by NACA and the Pollution Control Authority.
	• Need to engage farmers and improve enforcement of current DOF regulations governing effluent discharge.	• Attempts by DOF to organise farmers into cooperative groups to encourage coordinated effluent release and to discourage the release of poor quality effluent.
Feeds and feed management	• Poor feed conversion ratios on some farms. • Need to improve quality of feeds, food conversion and improve digestibility.	• Current research by DOF, CP and Aquastar.
	• Poor knowledge of dietary requirements of shrimp.	• Current research by NICA, CP and Aquastar.
	• Insufficient information on the types of plankton most suitable for shrimp feeds and the methods for promoting the growth of such plankton so that natural productivity can contribute maximally to production. • Inadequate knowledge of pond ecology and methods of manipulation to produce blooms of species of phytoplankton suitable for food.	• Current research by NICA, CP and Inst. of Aquaculture.
	• Inadequate diagnostic techniques for most shrimp diseases.	• Research by CP, NICA and the Aquatic Resources Research Institute (ARRI).
	• Ill-defined relationship between disease outbreaks and stress factors such as water quality and overcrowding. • Absence of an understanding of the role that sediment quality plays in stress in shrimp and disease development.	• Research by CP and Aquastar.

Table 12. (cont'd) Impediments to the development of a sustainable shrimp farming industry in Thailand and the research into these impediments, or the measures taken to address them.

Category	Impediments to a sustainable shrimp aquaculture industry	Current or recent research in Thailand, or remediation measure[a]
Feeds and feed management (cont'd)	• Lack of clear signs of disease in shrimp that often makes disease recognition by farmers difficult and belated. • Potential impacts of disease-causing micro-organisms on wild shrimp populations. • Inadequate knowledge of the immune system of shrimp. • Absence of disease-resistant stock.	• Research by CP, NICA, Aquatic Animal Health Research Institute (AAHRI) and Aquastar. • Research by CP, NICA, AAHRI, ARRI and Aquastar. • Research by CP, NICA, AAHRI and ARRI.
Antibiotic and chemotherapeutic use	• Need to improve preventative techniques for disease control and increase farmer awareness of safe chemical use.	• Ongoing education of farmers by DOF and CP. • Education by DOF officers. • Ongoing monitoring and education program by DOF.
Sediment	• Inadequate knowledge of the composition of sediment and its effect on pond ecology. • Need to adopt environmentally sound methods for disposal of pond-bottom sediment.	• Some study by DOF, Aquastar and Instit. of Aquaculture into composition.
Siting of farms	• Clustering of farms increasing demand on water resources and risk of self-pollution. • Construction of farms along water bodies with restricted flushing.	
Environment	• Siting of farms in mangrove conservation areas and national parks. • Use of water at non-ambient salinities. • Salinisation effects, including lands surrounding shrimp farms caused by farm seepage etc. • Risk of hypernutrification of coastal waters, canals and estuaries from untreated effluent and lack of data on the nutrient levels in water in shrimp farming areas.	• Considerable efforts by Government, DOF, and the private sector to prevent conversion of mangroves to ponds. • Study of the spread of salinity to rice fields by Maneepong (1993), Department of Geology, Prince of Songkhla University. • Ongoing monitoring program by Aquastar. Study by NACA and Pollution Control Department is about to begin.

Table 12. (cont'd) Impediments to the development of a sustainable shrimp farming industry in Thailand and the research into these impediments, or the measures taken to address them.

Category	Impediments to a sustainable shrimp aquaculture industry	Current or recent research in Thailand, or remediation measure[a]
Environment (cont'd)	• Lack of identification of the ecological impacts of shrimp culture on coastal and estuarine waters as a result of effluent discharge. • Lack of information on impacts on mangroves. • Need for land reclamation strategies for failed shrimp farms • Absence of integrated planning of coastal region development. • Need for environmental assessment or evaluation before the construction of most farms. • No knowledge of the ideal ratio of shrimp farms to other land uses to maintain ecological integrity. • Aesthetic changes in the landscape.	• Aquastar has performed environmental impact studies prior to extensive farm construction.
Education	• Inadequate educational support for farmers to make them aware of new research findings and improved farm management practices. • Lack of available information of farming practices which are most environmentally sound, and lack of support to implement practices. • Need for qualified and well-trained consultants to advise farmers on problems.	• Ongoing education programs by DOF, CP and Aquastar.
Hatcheries	• Need to improve quality and disease status of hatchery-reared postlarvae. • Reliance on wild-caught broodstock. • Need for a reliable test to determine the health of postlarvae and consequently to predict survival rates in rearing ponds.	• Research by Briggs (1992), Inst. of Aquaculture. Aquastar and AAHRI have also developed useful guidelines.

Table 12. (cont'd) Impediments to the development of a sustainable shrimp farming industry in Thailand and the research into these impediments, or the measures taken to address them.

Category	Impediments to a sustainable shrimp aquaculture industry	Current or recent research in Thailand, or remediation measure[a]
Production	• Prevalence of high stocking densities.	• Aquastar are currently deciding what stocking density to recommend to farmers which will compensate for their tendency to stock above recommended levels (D. Fegan, pers. comm.).
	• Need to improve pond management practices. • Lack of a method for determining a pond's carrying capacity. • Absence of integrated or mixed species farms.	
	• Reliance on *Penaeus monodon* in intensive farming.	• Aquastar is investigating the use of alternative species.
Economic	• Need for economic assessments of the reduction in agricultural land, including salinisation and direct conversion to shrimp farms.	
	• Need for economic assessments and management strategies for the industry with consideration of social and environmental issues.	• There has been a study of a single area by Jitsanguan et al. (1993) using some environmental values.
	• Tendency of farmers to look at short-term profit rather than at sustained, long-term production.	
	• Lack of evaluation of the economic impact of mangrove and wetland conversion.	• Study by Bannarlung (1990), Kasetsart University, of the foregone economic benefits of mangrove products when forests are cleared for shrimp farms.
Social	• Need for assessment of socio-cultural impacts of shrimp farm development.	• Sirisup (1988) studied Chantaburi Province.
	• Need for an assessment of conflicts between shrimp farmers and other resource users, and strategies to resolve conflicts.	• Some study of particular locations by postgraduate university students.
	• Need to improve access of information to members of the public on the issues affecting shrimp farming (currently lacking, with the exception of occasional newspaper articles).	
General	• Need for farmer cooperatives which have the potential to bring about the formulation of solutions to regional problems.	• DOF has organised a small proportion of farmers into cooperative groups.

[a] These were identified by reviewing current literature and from information given by representatives of the listed research organisations. [b] This Institute has a series of ongoing projects in Thailand. [c] Marine Resources Assessment Group, Imperial College, London. (Thai study by Ms V. Cowan.)

There is also a distinct need for a thorough investigation of the bacterial populations of ponds that break down metabolites, chemicals and solid wastes. The development and maintenance of healthy populations of beneficial micro-organisms may provide an effective and cheap method of in-pond water treatment. The effects of routine use of antibiotics and chemicals such as lime and chlorine on the populations of these bacteria requires investigation. Furthermore, research is needed into the role of the maintenance of particular microbe populations in preventing the proliferation of pathogenic microbes. Simple ecological manipulations of microbial populations could provide a tool for the control of some pathogens.

A further area of research that has been largely neglected is the level of chemical pollutants in source water. The collapse of the shrimp farming industry in the Gulf of Thailand in 1988 was attributed in part to the presence of industrial and agricultural pollutants in the waters supplying farms. High levels of some pesticides were found in the waters of Rayong Province in 1990 when extensive, acute shrimp mortalities occurred (Anon. 1994d). However, no comprehensive studies have been performed to determine chemicals present in most areas, nor assessment of the effect of such compounds on shrimp health or growth.

The occurrence of 'red tides' in the Gulf of Thailand requires study. These prevent farm water exchange and consequently bring about a deterioration in pond water quality which compromises shrimp health. There is a need for research into the reasons for these phytoplankton blooms, and for prediction of their occurrence and duration so that farmers can coordinate water exchange.

The development of 'closed systems' where water is recycled is currently receiving much attention and is seen by many as a means of overcoming problems of pollution of the external water supply and avoiding the effects of red tides. However, these systems will always rely on the input of some water to compensate for evaporative and seepage losses and to counteract hypersalinity induced by evaporation. Therefore, source water of reasonable quality will continue to be important, particularly at intensive stocking densities.

Effluent

The discharge of untreated effluent water into receiving waters can cause hypernutrification and self-pollution of farms. This can be overcome by the development of effective water treatment methods. Settlement ponds are recommended by DOF for water treatment. However, more comprehensive studies are needed to assess the efficiencies of these ponds in removing nutrients, suspended material and farm chemicals. Studies need to examine the appropriate sizes and depths of such ponds and the optimal retention times for water of different qualities. If they are proven to be effective, research is also needed to determine how these ponds could be incorporated into existing farms, especially into small farms which make up the majority of Thailand's production units. Research into appropriate engineering methods to service clusters of these small farms may be useful.

There has been, and continues to be, research into biological methods of effluent water treatment. However, this seems to have been directed toward large-scale experiments examining a fairly limited range of species. Despite the recognised shortcomings of species already examined, there seems to be few attempts to assess the capacities of alternative organisms. Research examining a range of new species is needed to find ones more suitable for the conditions in treatment ponds.

Also, studies have to be made of the capacity of natural or artificial wetlands to assimilate farm wastes. All biological treatment experiments to date concentrate on the ability of one or a few organisms to act in a steep-sided, flat-bottomed pond or canal rather than the use of a complex and integrated ecosystem.

Further, a number of bacterial and enzyme 'bioremediation' products are commercially available to treat aquaculture effluent. Research is under way into the effectiveness of these products.

Feeds and feeding

The dietary needs of shrimp are not completely known. Consequently, feeds are often fortified with a range of vitamins and other supplements to guard against possible deficiencies. This may be wasteful, and is being addressed by the feed producers, Charoen Pokphand (CP) and the Aquastar Company, and by the National Institute of Coastal Aquaculture who are examining the effects of various feeds on shrimp health and growth. These organisations are also trying to determine how to obtain optimal FCRs and are examining various species of phytoplankton for their suitability as shrimp feed. However, before such knowledge can be beneficial to the industry, there needs to be a better understanding of pond ecology so that environmental manipulation can be used to stimulate appropriate phytoplankton blooms.

Disease

Like water quality, shrimp diseases are well researched, however the wide range of diseases which affect shrimp farming make them a priority for research. Currently, attention is directed toward disease identification, the development of new diagnostic tests, disease treatments and improved knowledge of the immune system of shrimp. There is also a great deal of attention being given to the development of disease-resistant stock.

There still seems to be little study of the role of specific water quality parameters or sediment quality and disease. Also, little consideration has been given to the role of a healthy bacterial population in the pond or a healthy gut and intestinal flora to either disease development or the level of immunity in shrimp.

An interesting finding of researchers at CP suggests another potential avenue for disease research. Trials at CP demonstrated that extracts of an indigenous plant improved the resistance of shrimp to viral disease when added to pond water (B. Withyachmnarnkul, pers. comm.). Research into the reason for the effectiveness of this plant in enhancing immunity may contribute much to the understanding of the development of viral disease and to understanding the functioning of the shrimp immune system. Research to discover other naturally occurring immunoenhancers should be considered

Antibiotic use

The use of antibiotics has the potential to induce the evolution of antibiotic resistance in disease-causing micro-organisms, to disrupt the natural pond microbial ecology and to contaminate the flesh of prawns at the time of harvest. DOF has an ongoing monitoring program to ensure that harvested prawns destined for export to particular countries with strict antibiotic residue regulations meet these regulations. Farmers need to be made aware of the appropriate uses and dosages, and withdrawal times.

Sediment

Shrimp farmers often remove sediment from ponds at the end of the production cycle. The purported benefits of this process have not been clearly demonstrated. Research into this is needed.

Pond sediment contains organic matter, residues of antibiotics and other chemicals used in production, bacterial propagules and viruses, may be acid in reaction, and is saline. Shrimp farms in two districts in Thailand over a 40 km length of coastline were estimated to produce 2.72 million cubic metres of sediment annually. There is a need to develop improved methods for its disposal or treatment. Possible economic uses of sediment would also be extremely worthwhile. There has been talk of processing the sediment for use as an agricultural fertiliser, but as it is generally high in salinity, processing would require salt removal. Appropriate methods to perform this need to be developed.

Siting of farms

Farms in some areas are located on unsuitable sites, e.g. where there is an inadequate water supply, on estuaries and canals with restricted tidal flushing, or where they interfere with ground and surface water flows. Farms are also constructed at densities too great for the carrying capacity of the environment. This is a problem that can only be solved by the introduction (and enforcement) of legislation governing pond siting, and the development of management practices which increase the efficiency of water resource use. Such approaches must be based on thorough environmental assessment together with evaluation of economic and social factors.

Shrimp farms which are no longer used may leave land unfit for agriculture. In cases where ponds were constructed in areas of natural habitat, the extreme physical and biological alteration of the soil in the course of farm operation may inhibit succession of natural communities. Methods of remediating land left idle after shrimp farming are required—either to allow it to be used for agriculture or to return it to the type of habitat that previously existed. The growing experience on rehabilitation of mangroves needs to be further expanded.

Environment

Research is needed to develop integrated coastal zone management policies based on regional geographic, hydrological, ecological, economic and social considerations. Most importantly, research needs to be carried out to determine the appropriate total shrimp farming area for each region and how it should be balanced by other land uses for maximum socioeconomic benefit and to maintain ecological integrity.

Education

Widespread education of farmers on good management practices is required. Several studies have shown that many farmers do not have access to information sources. This is one of the greatest obstacles to change within the production sector of the shrimp industry and therefore to the development of more sustainable practices. The Government organisation responsible for extension work is DOF. Private organisations also have education programs. More effective programs and systems of information dissemination need to be developed. Research is needed into how this can be achieved.

Hatcheries

Many of Thailand's hatcheries use practices which result in the production of postlarvae which are not vigorous enough to have high survival rates in grow-out ponds. Research is needed into hatchery techniques that produce strong, healthy postlarvae. There is also a need for the development of a reliable test to determine the health of postlarvae prior to release into grow-out ponds.

Production

Improving production methods can only be addressed by better education and, where appropriate, enforced regulation and better self-regulation. Additionally, research is needed into the development of guidelines on the carrying capacity of ponds of various types and sizes under different environmental conditions.

Currently shrimp farm production in Thailand is predominantly from high density monoculture. Intensive monoculture crops are known to be more vulnerable to disease outbreaks and to place more demands on the environment than mixed crops. Research into the development of mixed culture systems could provide alternative methods of production which have less impact on the environment and in which shrimp are less prone to disease.

Despite the fact that there are many other shrimp species that have the potential to be reared under aquaculture conditions, it is *P. monodon* that is almost always produced from intensive aquaculture in Thailand. Research needs to be performed into the use of alternative shrimp species. The growth of a range of species would reduce the relative uniformity of shrimp genetics and disease, thus making it less likely that entire areas of production would be wiped out by particular disease outbreaks, as commonly occurs now. It may be found that some species are more suitable to culture under particular conditions than others or provide farmers with higher profitability.

Economic assessment

The potential for large and quickly-realised profit has directly driven the development of the shrimp farming industry. However, research into the cost–benefit of this development would be useful in helping guide future development strategies.

Social aspects

Focused research on the socio-cultural impacts of shrimp farming would be useful in determining the social benefits and costs of shrimp farm development, and also help guide future policy development.

Table 13. Summary of the research necessary to address issues of sustainability of the Thai shrimp aquaculture industry

- The relationship between the quality of sediment in ponds, farm management practices and water quality.
- The role of microbial populations in water quality improvement in rearing ponds and the effect of currently used antibiotics, chemotherapeutics, water treatment chemicals etc. on these.
- The role of beneficial microbes in controlling pathogenic organisms.
- The role, if any, of a healthy cuticle and gut flora and healthy microbial populations in pond water on enhancing disease resistance in shrimp.
- Identification of industrial and agricultural chemical pollutants in farm source water and their effects on shrimp growth and health.
- Prediction of the occurrence of red tides and identification of reasons for their occurrence.
- Assessment of the capacity of settlement ponds to improve pond effluent water quality. Investigation of the efficiency of ponds of various sizes and depths to improve water quality in different production situations.
- Assessment of the capacity of a range of plants and animals to remove wastes and chemicals from effluent water.
- Examination of the capacity of natural and artificial wetlands to treat effluent water.
- Improved understanding of pond ecology so that natural production of planktonic organisms suitable for shrimp food may be promoted by environmental manipulation.
- Research into naturally occurring immunoenhancers and determination of the reasons for their effect.
- Examination of the role of water quality in the development of various diseases.
- Examination of sediment composition and methods of disposal and treatment.
- Development of site assessment procedures to determine areas suitable for farm construction.
- Development of integrated coastal zone management policies.
- Development of methods to remediate land after shrimp farms have failed.
- Identification of appropriate zones for shrimp farming in particular regions so that the environmental carrying capacity is not exceeded.
- Identification of effective methods of transmitting to farmers current research findings and information regarding farm management practices.
- Improved hatchery techniques.
- Research into domestication of broodstock so that it is possible to select for desirable, inheritable characteristics.

Table 13. (cont'd) Summary of the research necessary to address issues of sustainability of the Thai shrimp aquaculture industry

- Research into alternative species (to *Penaeus monodon*) for intensive and semi-intensive culture.
- Experiments with mixed culture.
- Economic rationalism of the industry with full assessment of environmental and social issues.
- Market price and demand forecasts.
- Research into the social impacts of coastal shrimp farming.

Conclusions about constraints

Research can contribute to the development of a sustainable shrimp aquaculture industry in Thailand. This research will need to be well coordinated and well disseminated. Addressing only one or two of the priority areas in Table 13 may not significantly improve current industry sustainability, because issues are interrelated or interdependent.

It is necessary for shrimp farm research that a coordinated and integrated approach is formulated. This must be fitted within the framework of the existing research bodies in Thailand and collaborating overseas institutions. Finally, the role of the Government of Thailand in embracing the research findings is fundamental to the future of the industry.

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References

Anon. 1994a. Target of B1.3 trillion set for next year's exports. Business Post, Bangkok Post, 6 November 1994.

Anon. 1994b. Mystery plague kills VN shrimp. Bangkok Post, 9 December 1994.

Anon. 1994c. Global shrimp production review. C.P. Shrimp News, 2(2), 1.

Anon. 1994d. Asian Shrimp News, 3rd Quarter.

Anon. 1994e. New brine irrigation system funded. Bangkok Post, 10 October 1994.

Anon. 1995a. Polluted water killing farm-bred tiger prawns. Bangkok Post, 28 January 1995.

Anon. 1995b. Shrimp farms bounce back. Fish Farming International, 22, 1.

Anon. 1998a. Shrimp culture newsletter. C.P. Group (in Thai).

Anon. 1998b. Thailand. World shrimp farming 1998. In: Rosenberry, B., ed., Shrimp News International, 160–174.

Apud, F., Primavera, J.H. and Torres, Jr, P.L. 1989. Farming of prawns and shrimps. Aquaculture extension manual, No. 5, third edition. Tigbauan, Iloilo, Philippines, Southeast Asian Fisheries Development Center, Aquaculture Department, 66p.

Bannarlung, A. 1990. Economic value of mangrove output and the use of mangrove for shrimp production. A case study of Bandon Bay. Graduate Research, Kasetsart University.

Barde, J.-P. and Pearce, D.W. (ed.) 1991. Valuing the environment. Six case studies. London, Earthscan Publications, 265p.

Barg, U.C. 1992. Guidelines for the promotion of environmental management of coastal aquaculture development (based on review of selected experiences and concepts). Food and Agriculture Organization of the United Nations (FAO) Fisheries Technical Paper No. 328. Rome, FAO, 122p.

Baticados, M.C.L., Lavilla-Pitogo, C.R., Cruz-Lacierda, E.R., de la Pena, L.D. and Sunaz, N.A. 1990. Studies on the chemical control of luminous bacteria *Vibrio harveyi* and *V. splendidus* isolated from diseased *Penaeus monodon* larvae and rearing water. Diseases of Aquatic Organisms, 9, 133–139.

Boonyapiwat, S. 1989. Species of phytoplankton in the occurrence of red tides in the Gulf of Thailand. The Proceedings of the Fourth National Conference of Marine Science, Coastal Resource Section, 9p.

Boromthanarat, S. 1994. Coastal zone management. In: Workshop on environmental assessment and management of aquaculture (draft report). Third Meeting of the Technical Advisory Committee (TAC-3) of the Network of Aquaculture Centres of Asia–Pacific, Hanoi, S.R. Vietnam, 27–30 September 1994, III, 10–14.

Boyd, C.E. 1989. Water quality management and aeration in shrimp farming. Fisheries and Allied Aquacultures Departmental Series No. 2. Alabama, USA, Auburn University, 183p.

Briggs, M.R.P. 1992. A stress test for determining vigour of post-larval *Penaeus monodon* Fabricius. Aquaculture and Fisheries Management, 23, 633–637.

Briggs, M.R.P. 1993a. Water quality and treatment in sustainable shrimp farming. Paper presented at the Tenth Year Anniversary Conference of the Tinsulanonda Songkhla Fisheries College, Songkhla, Thailand, 2–4 June 1993, 35p.

Briggs, M.R.P. 1993b. 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, 20p.

Briggs, M.R.P. and Funge-Smith, S.J. 1993. A nutrient budget of some intensive marine shrimp ponds in Thailand. Aquaculture and Fisheries Management (in press).

Briggs, M.R.P. and Funge-Smith, S.J. 1994. Unsustainable shrimp culture—causes and potential solutions from experience in Thailand. Appendix 2. In: Development of strategies for sustainable shrimp farming. Final report to the Overseas Development Administration. Stirling, Scotland, Institute of Aquaculture, University of Stirling, 31p.

Brooks, D. 1990. Beyond the catch phrases: what does sustainable development really mean? International Development Research Center (of Canada) Reports, 18, 24–25.

Chaiyukum, K., Songsangjinda, P. and Tanvilai, D. 1992. Water quality and production of two management systems in intensive shrimp farms in the Songkla area. National Institute of Coastal Aquaculture, Songkhla, Thailand. Department of Fisheries Technical Paper, 11, 14p.

Chaiyakum, K. and Tanvilai, D. 1989. Use of mussel and *Gracilaria* to treat the effluent water from intensive shrimp ponds. National Institute for Coastal Aquaculture, Songkhla, Thailand. Department of Fisheries Technical Paper, 1, 26p.

Chanratchakool, P., Turnbull, J.F., Funge-Smith, S.J., MacRae, I.H., Limsuwan and C. 1998. Health management in shrimp ponds. Bangkok, Aquatic Animal Health Research Institute, Kasetsart University, 152p.

Chanratchakool, P., Turnbull, J. and Limsuwan, C. 1994. Health management in shrimp ponds. Bangkok, Aquatic Animal Health Research Institute, Department of Fisheries, Kasetsart University Campus, 89p.

Chen, S.N. 1990. Collapse and remedy for the shrimp culture industry in Taiwan. Taiwan, Department of Zoology, National Taiwan University.

Chiang, H.C. and Lee, J.C. 1986. Study of the treatment and re-use of aquacultural wastewater in Taiwan. Aquacultural Engineering, 5, 301–312.

Chien, Y.H. 1992. Aquaculture in the Republic of China: a biosocioeconomic analysis of the aquaculture industry in Taiwan. In: Aquaculture in Asia. Proceedings of the 1990 Asian Productivity Organization (APO) Symposium on Aquaculture, Taiwan Fisheries Research Institute. Tokyo, APO, 31–50.

Chindanon, A. 1991. Report of the occurrence of red tides in the Gulf of Thailand and the surveillance plan of the Department of Fisheries in the occurrence of red tides. Bangkok, The Department of Fisheries, 8p.

Chintatum, T. 1991. Today's fisheries world. Aquatic Fauna, 2, 107–108.

Csavas, I. 1988. Shrimp farming development in Asia. In: Shrimp '88, Bangkok, Thailand, 26–28 January 1988. Kuala Lumpur, Malaysia, Infofish, 63–92.

DOF (Department of Fisheries) 1992. Experiments on green mussel, *Mytilus* sp., and seaweed, *Gracilaria* sp. for biological wastewater discharge treatment from intensive shrimp ponds. Bangkok, National Institute of Coastal Aquaculture, Department of Fisheries Technical Paper No. 5, 24p.

DOF (Department of Fisheries) 1994. Country paper: Thailand. ASEAN (Association of South-East Asian Nations) Conf/Policy/6. Conference on Fisheries Management and Development Strategies for the ASEAN Region for the Year 2000, Bangkok, Thailand. Bangkok, DOF, Ministry of Cooperatives, 22p.

Dixon, J.A., Carpenter, R.A., Fallon. L.A., Shermann, P.B. and Manopimoke, S. 1988. Economic analysis of environmental analysis of development projects. London, Earthscan Publications, 125p.

Dovers, S. and Handmer, J. 1994. Contradictions of sustainability. The concept of sustainability is riddled with conflicts and paradoxes. Tropical Forest Update, 4(2), 4–5.

FAO (Food and Agriculture Organization of the United Nations) 1991. Environment and sustainability in fisheries. COFI/91/3. Document presented at the 19th Session of the Committee on Fisheries, 8–12 April 1991, Rome, Italy, 23p.

Fast, A.W., Carpenter, K.E., Estilo, V.J. and Gonzales, H.J. 1988. Effects of pond depth and artificial mixing on dynamics of Philippines brackishwater shrimp ponds. Aquacultural Engineering, 7, 349–361.

Fegan, D.F. 1994. Environmental assessment and management of aquaculture development: an industry perspective. In: Workshop on environmental assessment and management of aquaculture (draft report). Third Meeting of the Technical Advisory Committee (TAC-3) of the Network of Aquaculture Centres of Asia–Pacific, Hanoi, S.R. Vietnam, 27–30 September 1994, III, 18–29.

Flegal, T. 1992. Insecticide danger to shrimp. Letter cited in Aquaculture News from Around the World. Infofish, 6, 36.

Flegel, T.W. 1996. A turning point for sustainable aquaculture: the white spot virus crisis in Asian shrimp culture. Aquaculture Asia, July–September, 29–34.

Funge-Smith, S. 1997. Thailand. World shrimp farming 1997. In: Rosenberry, B., ed., Shrimp News International, 142–154.

Hirasawa, Y. 1992. Economic analysis of prawn culture in Asia. In: Aquaculture in Asia. Proceedings of the 1990 Asian Productivity Organization (APO) Symposium on Aquaculture. Taiwan Fisheries Research Institute, 201–222.

Hopkins, J.S., Stokes, A.D., Browdy, C.L. and Sandifer, P.A. 1991. The relationship between feeding rate, paddlewheel aeration rate and expected dawn dissolved oxygen in intensive shrimp ponds. Aquacultural Engineering, 10, 281–290.

Jacobs, M. 1991. The Green Economy. London, Pluto Press.

Jitsanguan, T., Mungkin, N. and Claithong, W. 1993. Sustainable coastal resource management in Thailand: the case study of shrimp cultivation at Pak Panang Bay. Research paper submitted to Asian Fisheries Social Science Research Network (AFSSRN), Thailand, 106p.

Kakorkin, C. and Sunaryanto, A. 1994. Why do some shrimp farms fail? Eurasian Aquaculture, 4, 7–8.

Kapetsky, J.M. 1987. Conversion of mangroves for pond aquaculture: some short-term and long-term remedies. In: Report of the workshop on the conversion of mangrove areas to aquaculture, Iloilo City, Visayas, Philippines, April 24–26 1986. UNDP/UNESCO (United Nations Development Programme/United Nations Educational Scientific and Cultural Organization) Regional Project on Research and its Application to the Management of the Mangroves of Asia and the Pacific, New Delhi, India, March 1987, 96–106.

Katesombun, B. 1992. Aquaculture promotion: endangering the mangrove forests. In: The future of people and forests after the logging ban. Bangkok, Project for Ecological Recovery, 103–122.

Keawchum, S. 1993. Application of effective micro-organisms in intensive shrimp (*P. monodon*) culture system. MSc thesis proposal. Bangkok, Asian Institute of Technology, 32p.

Kongkeo, H. 1989. Farm management and techniques of marine shrimp culture in Thailand. In: Proceedings of the Southeast Asia Shrimp Farm Management Workshop, Philippines, Indonesia, Thailand, 26 July–11 August 1989, 127–133.

Kongkeo, H. 1995. How Thailand became the largest producer of cultured shrimp in the world. Infofish (in press).

Kungvankij, P., Tiro, L.B., Pudadera, B.J., Potestas, I.O., Corre, K.G., Borlongan, E., Talean, G.A., Bustio, L.F., Tech, E.T., Unguii, A. and Chua, T.E. 1986. Shrimp hatchery design, operation and management. Network of Aquaculture Centres in Asia (NACA), Regional Lead Centre in the Philipines. NACA Training Manual Series No. 1.

Liao, I.-C. 1989. *Penaeus monodon* culture in Taiwan: through two decades of growth. International Journal of Fish Technology, 1, 16–24.

Liao, I.-C. 1990. The world's marine prawn culture industries: today and tomorrow. In: Hirano, R. and Hanyu, I., ed., The second Asian fisheries forum. Manila, Philippines, Asian Fisheries Society, 11–17.

Lin, C.K. 1998. Low-salinity inland shrimp farming: how it is done. In: Rosenberry, B., ed., World shrimp farming. San Diego, Shrimp News International, 11, 168–169.

Lin, C.K. 1989. Prawn culture in Taiwan: what went wrong? World Aquaculture, 20, 19–20.

Lin, C.K., Ruamthaveesub, P. and Wanuchsoontorn, P. 1991. Wastewater of intensive shrimp farming and its potential biological treatment. In: Polprasert, C., Yang, P.Y., Kongricharoern, N. and Kanjanaprapin, W., ed., Proceedings of the Seminar/Workshop on Agro-based Wastewater Treatment and Recovery Systems. Bangkok, Environmental Engineering Division, Asian Institute of Technology, Bangkok, 12p.

Lohawanthanakal, C. 1993. Thailand: a progress report. World Shrimp Farming, 18(3), 5–6.

MacIntosh, D.J. and Phillips, M.J. 1992. Environmental issues in shrimp farming. In: de Saram, H. and Singh, T., ed., Shrimp '92. Proceedings of the 3rd Global Conference on the Shrimp Industry, Hong Kong, 14–16 September 1992. Kuala Lumpur, Infofish, 118–145.

Maneepong, S. 1993. Pattern of salinity spreading from shrimp ponds to rice fields. Songkhla, Thailand, Department of Geology, Faculty of Natural Resources, Prince of Songkhla University.

Marsden, D. 1990. The meaning of social development. In: Marsden, D. and Oakley, P., ed., Evaluating social development projects. Development Series No. 5. Oxford, Oxfam, 16–26.

MIDAS (Mekong International Development Associates) 1995. Pre-investment study for a coastal resources management program in Thailand. Interim report submitted to the World Bank and the Office of Agricultural Cooperatives of the Royal Thai Government, 162p.

Mittelmark, J. and Landkammer, D. 1990. Design and construction of diversion ponds for aquaculture. Department of Fisheries and Wildlife, University of Minnesota, 24p.

Moriarty, D.J.W. 1986. Bacterial productivity in ponds used for culture of penaeid prawns. Microbial Ecology, 12, 187–190.

NACA (Network of Acquaculture Centres in Asia–Pacific) 1994a. Impact of shrimp farming on the environment: study 1. Sixth Meeting of the Governing Council (GCM-6) of NACA, Beijing, China, 162p.

NACA (Network of Acquaculture Centres in Asia–Pacific) 1994b. The environmental management of coastal aquaculture. Study of shrimp culture in Samut Sakhon and Chantaburi Provinces. Bangkok, Thailand, NACA, 195p.

Nakalak, C. 1994. Fishery statistics of Thailand. In: Proceedings of the Regional Workshop on Fishery Information and Statistics in Asia, Volume II. Bangkok, Southeast Asian Fisheries Development Center, 261–268.

Nash, G., Anderson, I.G. and Shariff, M. 1988. Pathological changes in the tiger prawn, *Penaeus monodon* Fabricius, associated with culture in brackishwater ponds developed from potentially acid sulphate soils. Journal of Fish Diseases, 11, 113–123.

OECF (Overseas Economic Cooperation Fund of Japan) 1992. Thailand environmental profile, Volume I. Helsinki, Finland, Soil and Water Ltd.

OEPP (Office of Environmental Policy and Planning) 1994. The environmental management of coastal aquaculture. An assessment of shrimp culture in Samut Sakhon and Chantaburi Provinces. Prepared for OEPP by the Network of Aquaculture Centres in Asia–Pacific (NACA). Bangkok, NACA, 195p.

Office of Agricultural Economics 1991. The enterprise of giant prawn culture in Thailand. Agricultural Economics Division Technical Paper, 54, 107p.

Office of National Statistics 1990. Report on survey of costs and returns of semi and intensive shrimp farming in 1990. Office of Prime Minister, 69p.

Paw, J.N., Bunapapong, S., White, A.T. and Sadorra, M.S.S. 1988. The coastal environment profile of Ban Don Bay and Phangnga Bay, Thailand. Association of South-East Asian Nations/United States Coastal Resources Management Project. Technical Publications Series 2, 75p.

Phillips, M.J. 1992. Environmental aspects of shrimp culture in Thailand. Report for the Asian Development Bank Review Mission on Loan No. 787–THA: Brackishwater Shrimp Culture Development Project, 11p.

Phillips, M.J., Kwei Lin, C. and Beveridge, M.C.M. 1993. Shrimp culture and the environment: lessons from the world's most rapidly expanding warm water aquaculture sector. In: Pullin, R.S.V., Rosenthal, H. and Maclean, J.L., ed., Environment and aquaculture in developing countries. ICLARM (International Centre for Living Aquatic Resources) Conference Proceedings, 31, 171–197.

Piamsomboon, S. 1993. Shrimp farming, and advantages for socioeconomics. In: A conference on the positive impact of shrimp farming on ecology of coastal water and Thai economics, 31 January 1993, Hadkoaw Resort, Songkhla, Thailand. Thailand, Department of Fisheries, 35–62.

Poernomo, A. 1990. Site selection for coastal shrimp ponds. In: Technical and economic aspects of shrimp farming. Proceedings of the Aquatech '90 conference, Kuala Lumpur, Malaysia, 11–14 June 1992. Kuala Lumpur, Malaysia, Infofish, 3–19.

Pollution Control Department 1997. A survey of water pollution from coastal aquaculture. Report of a study by the Network of Aquaculture Centres in Asia–Pacific submitted to the Pollution Control Department of the Ministry of Science and Technology of Thailand, Bangkok, 208p.

Primavera, J.H. 1989. The social, ecological and economic implications of intensive prawn farming. SEAFDEC (Southeast Asian Fisheries Development Center) Asian Aquaculture, 111, 1–6.

Ragunathnan, S. and Hambrey, J.B. 1997. Thailand. World shrimp farming 1996. In: Rosenberry, B., ed., Shrimp News International, 79–87.

Raksakul, S. 1994. Prawn farming: riches and ruins. Sunday Post, Bangkok, November 13 1994, 20–21.

Robertson, A. and Phillips, M.J. 1995. Mangroves as filters of shrimp pond effluent: predictions and biogeochemical research needs. Hydrobiologia, 295, 311–321.

Shariff, M. and Subasinghe, R. 1992. Aquarium fish health—do we really care? Infofish International, 6, 43–47.

Sirisup, S. 1988 Socio–economic changes in the course of commercialisation. Coastal aquaculture in Chantaburi Province, Thailand. Masters thesis. Bangkok, Asian Institute of Technology.

Smith, P. 1993. Prawn farming in Australia—sediment is a major issue. Australian Fisheries, December 1993, 29–32.

Smith, P.T. 1995. Characterisation of the effluent from prawn ponds on the Clarence River, Australia. In: Proceedings of Sustainable Aquaculture 95, PACON (Pacific Congress on Marine Science and Technology) International, 327–338.

Smith, P.T. 1996a. Physical and chemical characteristics of sediments from prawn farms and mangrove habitats on the Clarence River, Australia. Aquaculture, 146, 47–83.

Smith, P.T. 1996b. Toxic effects of blooms of marine species of Oscillatoriales on farmed prawns (*Penaeus monodon*, *Penaeus japonicus*) and brine shrimp (*Artemia salina*). Toxicon, 34, 857–869.

Smith, P.T. 1998. Effects of removing accumulated sediments on the bacteriology of ponds used to culture *Penaeus monodon*. Asian Fisheries Science, 10, 355–370.

Snedaker, S.C. and Getter, C.D. 1985. Coastal resources management guidelines. Renewable resources information service. Coastal Management Publication No. 2. Colombia, Research Planning Institute.

Suraswadi, P. 1990. State of the Thailand shrimp industry. International Seafood Conference, Budapest, Hungary, 29 October 1990, 8p.

Tanasomwang, V. 1994. Marine shrimp culture in central Thailand. In: Proceedings of the Southeast Asian Aquatic Animal Disease Control Programme (SEAADCP) Prawn Health Management Workshop, 10–20 January 1994, 106p.

Therivel, R., Wilson, E., Thompson, S., Heaney, D. and Pritchard, D. 1992. Strategic Environmental Assessment. London, Earthscan Publications.

Tiensongrusmee, B. 1970. A present status of shrimp farming in Thailand. Invertebrate Fisheries Investigations, Marine Fisheries Laboratory, Division of Research and Investigations, Department of Fisheries, Bangkok, Thailand. Contribution No. 18, 34p.

Tookwinas, S. 1993. Intensive marine shrimp farming techniques in Thailand. In: Proceedings of the First International Symposium on Aquaculture Technology and Investment Opportunities, Riyadh, Saudi Arabia, 11–14 April 1993. Ministry of Agriculture and Water, King Abdulaziz City for Science and Technology and Riyadh Chamber and Industry, 230–240.

Tookwinas, S. and Leeruksakiat, P. 1994. Application of GIS technique for shrimp farm and mangrove forest development in Chantaburi Province, Thailand. Paper of Kung Krabean Bay Royal Development Centre, Klongkud Subdistrict, Thamai District, Chantaburi, Thailand, 25p.

Tookwinas, S., Malem, F. and Songsangjinda, P. 1993. Quality and quantity of water from intensive marine shrimp farms at Kung Krabean Bay, Chantaburi Province, Eastern Thailand. Kung Krabean Royal Development Study Centre (unpublished), 20p.

Turnbull, J.F. 1993. Preface to Dr D. Baird's report—Short-term statistical consultancy on the linkage between disease and water quality in farmed shrimp ponds. A report to the Overseas Development Agency's North East Sumateran Prawn Project. Stirling, Scotland, Institute of Aquaculture, Stirling University, i–iv.

Turnbull, J., Chanratchakool, P. and MacRae, I.H. 1994. Proceedings of the SEAFDEC Southeast Asian Aquatic Animal Disease Control Programme (SEAADCP) Prawn Health Management Workshop, 10–20 January 1994, 106p.

Wickens, J.F. 1985. Ammonia production and oxidation during the culture of marine prawns and lobsters in laboratory recirculation systems. Aquacultural Engineering, 4, 155–174.

World Commission on Environmental Development 1987. The world: our common future. Oxford, Oxford University Press, 400p.

In Search of Variables Contributing to Production of Shrimp and Identifying Shrimp Farming Provinces in Thailand

Than Pe and Paul T. Smith*

Abstract

In this paper, the 1995 survey data from 451 shrimp farms in Thailand were analysed using logistic regression and multiple analysis methods. Variables that could identify the 10 provinces practising prawn farming were determined by the method of logistic regression. The variables which play an important part in identifying the provinces are: dominant soil type; number of farming years; source of farm water; depth of production ponds; number of other aquaculture farms within 3 km of the farm; number of aquaculture farms sharing the water supply; number of farms discharging effluent into the water supply canal; preparation of an environmental impact assessment; site selection to avoid impacts of other users; design of a separate water supply/drainage system; retention of a mangrove buffer zone; use of an effluent treatment pond; existence of a water or sediment related problem; and other problems with salinity, feed quality and seed quality. The high proportion of variables relating to environmental aspects of shrimp farming is an important and interesting finding because it provides strong evidence to support the hypothesis that environmental problems are the cause of reduced productivity and incidence of disease in shrimp farms. The variables which contribute to the level of shrimp production (kg/ha/yr) were determined by the method of multiple regression and the key variables were: total overheads; total estimated fertiliser cost; total labour cost; total feed cost; seed cost; and total other input costs. It is recommended that in future, the design of surveys and format of the questionnaires could be improved to enable deeper analysis of data, especially with respect to environmental problems. Also it may be better to use 'pond' rather than 'farm' as the sample unit.

Introduction

The preliminary analysis of the survey data has been discussed elsewhere (see Smith 1999a,b) and in this chapter we have tried to extend the analysis by using advanced statistical methods as well as the application of the geographical information system (GIS). However, the analysis was limited by problems in the questionnaire, particularly with respect to missing values. To counter this, multiple regression analysis was used to estimate the missing values of some continuous economic variables using the relationship with other variables. Then a linear multiple regression model for shrimp production was developed. For categorical variables, general loglinear analysis was applied to study the relationship among the variables, in particular provinces and problem variables.

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In the preliminary analysis, the survey supported the working hypothesis that the shrimp farm industry in each coastal province of Thailand has distinctly different characteristics. To find the variables that would identify the provinces, logistic regression analysis was applied.

Results of the Analysis

General overview

From the survey data it was possible to use 276 variables, out of which 15 were descriptive (fixed), 36 were outcome (sustainability) variables, 118 were management (modifiable) variables, 54 were problem (identification) variables, 42 were economic (analysis) variables and the remaining 11 variables related to planning. The problem of non-response or missing values was very noticeable, particularly with regard to economic variables. Furthermore, due to the nature of the variables, many were categorical and some were continuous. This made it difficult to apply statistical methods where specific underlying assumptions had to be fulfilled. We therefore tried to analyse some variables separately, although it would give interesting results if they were analysed together. As the whole scope of results from this large survey could not be presented in one article, more analysis will be presented in the future, including results of studies on time-series aspects and analysis of differences in regions of Thailand, as well as making comparisons with the experiences of researchers in other countries.

In analysing the data, the main interest was to find the researchable issues in sustainable coastal shrimp aquaculture and to build models to describe the relationship between the production of shrimp and other factors. Another aspect was to find the variables or factors which would allow the provinces to be identified, particularly when the problems faced by the farmers in different provinces are not the same.

Initially the analysis tested the equality of average market production (kg/ha/yr) and feed conversion ratio (FCR) in the provinces and this showed that average market production in the provinces was different. The least significance difference (LSD) method was found to be the most sensitive method out of five methods available in the Statistical Package for Social Scientists (SPSS). By that method, Krabi Province, which had the highest average production level (16,035 kg/ha/yr), was different from all other provinces. Songkhla Province had the second highest average production level (12,067 kg/ha/yr) and was different from all other provinces except Krabi and Satun. Satun was the third highest province in average production and it was similar to Songkhla. The lowest in average production (4,622 kg/ha/yr) occurred in Phetchaburi Province and it was different from the other provinces except for Samut Sakhon (5,662 kg/ha/yr) and Chanthaburi (5,703 kg/ha/yr).

Average FCR was also found to be different when we tested simultaneously for all 10 provinces using the LSD method. Songkhla, which had the highest average FCR (2.51), was different from the provinces of Phetchaburi (1.78), Trat (1.66), Krabi (1.70) and Surat Thani (1.92). Chumphon, which had the second highest average FCR (2.30), was different from Phetchaburi and Trat. Other provinces were not significantly different in average FCR. From this, a crude picture of the situation in the provinces was obtained. The investigation of the four major regions in Thailand (i.e. central, eastern, south-western and southern) did not reveal extra useful information.

Relationship between problems and provinces

In the survey covering 10 provinces, 54 variables on problem identification were included. The key variables were: major problems; water or sediment related problems; disease problems; and other problems. The number of farms was reduced to eliminate those that consistently recorded 'no' to most questions under investigation and showed clear discrepancies in their responses. Thus, using 292 farms with complete data for the variables under study, the analysis revealed that 9.93% of the farms had all four types of problems and 13.01% had none of the problems, while the rest had at least one type of problem. The association between the provinces and all four problems was found to be significant even at the 1% level. This means that the association between the provinces and the problems was significant and serious.

The degrees of association between the provinces and 'major problem', 'water or sediment related problem', 'disease problem' and 'other problems' were 0.4533, 0.3863, 0.313 and 0.4253, respectively. 'Major problem' was significant in Chumphon, Chanthaburi, Samut Sakhon and Trat, whereas 'water or sediment related problem' was significant in Chanthaburi, Nakhon Sri Thamarat, Samut Sakhon (on the border), Songkhla and Surat Thani. 'Disease problem' was significant in Nakhon Sri Thamarat and Trat, whereas 'other problems' were significant in Krabi, Satun, Surat Thani and Trat.

As one might have expected, using general loglinear analysis, the hypothesis of independence of the problems was rejected since the observed significance levels associated with the likelihood ratio chi-square = 69.04 and Pearson chi-square = 74.71 were very small (2.E-10 and 2.E-11, respectively). This means that there exists a strong association between problems.

Identification of provinces by logistic regression analysis

The introduction of intensive shrimp farming in the provinces of Thailand occurred in stages after the initial farms were set up in Samut Sakhon. However, the oldest farms in the survey were from the eastern province of Trat, followed by the southern provinces of Surat Thani and Songkhla. Phetchaburi was the latest province, preceded by Samut Sakhon and Chumphon.

To determine the variables that would identify a province, the method of logistic regression was used, since the variable 'province' is categorical. For logistic regression, the probability of an event occurring was estimated using the model:

$$\text{Probability (event)} = 1/(1 + e^{-Z}) \qquad (1)$$

where $Z = b_0 + b_1 X_1 + b_2 X_2 + ... + b_p X_p$; in which case X_i, i = 1, 2,...p are independent variables, and b_i, i = 0, 1, 2,...p are constant coefficients to be estimated from the data.

The analysis initially included many (independent) variables that could contribute to identifying a province. Then, using the method of likelihood, the procedure deleted step-by-step those variables which were not significant. The process was repeated until all variables had been tested. The following results were obtained for each province.

Chanthaburi Province

The key variables which identified Chanthaburi were: type of soil (variable code = SOIL), and four variables relating to measures taken to reduce the impact on the farm, i.e. environmental impact assessment during planning (Q8_1), design of separate water supply/drainage system (Q8_4), number of aquaculture farms within 3 km of the farm (Q7_8) and number of farms discharging into water supply (Q7_10). It was possible to identify the farms in Chanthaburi Province from the total farms in the survey with an accuracy of 99.61% using only those five variables (see Appendix).

Trat Province

In this province the key variables were: major problem (Q2_3); three variables relating to measures taken to reduce the impact on the farm, i.e. site selection to avoid impacts on other users (Q8_2), effluent treatment pond (Q8_6) and other measures taken to reduce the impacts of the farm (Q8_7); the existence of water or sediment related problem (Q14PROB); other problems which have resulted in diminished harvest, loss of crop or missed crop (Q16OTH); and depth of production ponds (Q6_4). It was possible to identify the farms in Trat Province from the total farms in the survey with an accuracy of 93.82% using only those seven variables (see Appendix).

Chumphon Province

In this case, the key variables were: major problem (Q2_3); type of soil (SOIL); four variables relating to measures taken to reduce the impact on the farm, i.e. environmental impact assessment during planning (Q8_1), retention of mangrove buffer zone (Q8_5), number of aquaculture farms within 3 km of the farm (Q7_8), and number of farms discharging effluent into water supply (Q7_10); number of poachings over the past 3 years (Q16_6B); number of power cuts over the past 3 years (Q16_7B); number of years of farming (Q1_1); and depth of production ponds (Q6_4). It was possible to identify the farms in Chumphon Province from the total farms in the survey with an accuracy of 93.44% using only those 10 variables (see Appendix).

Krabi Province

The key variables were: three variables relating to measures taken to reduce the impact on the farm, i.e. design of separate water supply/drainage system (Q8_4), retention of mangrove buffer zone (Q8_5) and effluent treatment pond (Q8_6); and other problems which have resulted in diminished harvest, loss of crop or missed crop (Q16OTH). It was possible to identify the farms in Krabi Province from the total farms in the survey with an accuracy of 95.75% using only those four variables (see Appendix).

Nakhon Sri Thamarat Province

In this province the key variables were: seven variables relating to measures taken to reduce the impact on the farm, i.e. environmental impact assessment during planning (Q8_1), site selection to avoid impacts on other users (Q8_2), design of separate water supply/drainage system (Q8_4), other measures taken to reduce the impacts of the farm (Q8_7), number of aquaculture farms within 3 km of the farm (Q7_8), number of aquaculture farms sharing water supply (Q7_9) and number of farms discharging effluent into water supply canal (Q7_10); the existence of water or sediment related problem (Q14PROB); and feed quality problem over the past 3 years (Q16_4B). It was possible to identify the farms in Nakhon Sri Thamarat Province from the total farms in the survey with an accuracy of 93.44% using only those nine variables (see Appendix).

Phetchaburi Province

Petchaburi Province was different from most other provinces and, although the four variables which follow are included in the model, none of the farms from that province could be identified. Surprisingly, the farms not in Petchaburi Province could be identified perfectly using the four variables: source of salt water (WSALT); environmental impact assessment during planning (Q8_1); design of separate water supply/drainage system (Q8_4); and effluent treatment pond (Q8_6) (see Appendix).

Samut Sakhon Province

For Samat Sakhon, which had only one farm in the analysis, it was not possible to find a set of variables which could identify only that farm. However, by using just two variables—soil type (SOIL) and environmental impact assessment during planning (Q8_1)—it was possible to identify 99.61% of farms as being in the other provinces. This solution was not unique because other variables could be statistically determined which could also identify a high proportion of the farms as being in other provinces (see Appendix).

Satun Province

The farms in Satun Province could be identified from the total farms in the survey with an accuracy of 94.59% by using the following nine key variables: source of salt water (WSALT); three variables relating to measures taken to reduce impacts, i.e. site selection to avoid impacts on other users (Q8_2), number of aquaculture farms within 3 km of the farm (Q7_8) and number of farms discharging effluent into water supply canal (Q7_10); salinity problem over the past 3 years (Q14_1B); temperature problem over the past 3 years (Q14_2B); bacteria problem over the past 3 years (Q15_1D); feed quantity problem over the past 3 years (Q16_3B); and other problems which have resulted in diminished harvest, loss of crop or missed crop (Q16OTH) (see Appendix).

Songkhla Province

The key variables for this province were: number of years of farming at the site (Q1_1); major problem (Q2_3); four variables relating to measures taken to reduce the impact on the farm, i.e. site selection to avoid impacts of other users (Q8_3), design of separate water supply/drainage system (Q8_4), number of farms sharing water supply (Q7_9) and number of farms discharging effluent into the same water supply canal (Q7_10); seed quality problem over the past 3 years (Q16_2B); and feed quality problem over the past 3 years (Q16_4B). It was possible to identify the farms in Songkhla Province from the total farms in the survey with an accuracy of 92.28% using only those eight variables (see Appendix).

Surat Thani Province

The key variables for Surat Thani were: source of salt water; number of farming years at the site (Q1_1); major problem (Q2_3); depth of production ponds (Q6_4); four variables relating to measures taken to reduce the impact on the farm; i.e. environmental impact assessment during planning (Q8_1), site selection to avoid impacts on other users (Q8_2), design of separate water supply/drainage system (Q8_4) and number of aquaculture farms sharing the water supply (Q7_9); the existence of water or sediment related problem (Q14PROB); flooding problem over the past 3 years (Q14_10B); and other problems which have resulted in diminished harvest, loss of crop or missed crop (Q16OTH). It was possible to identify the farms in Surat Thani Province from the total farms in the survey with an accuracy of 89.58% using only those 10 variables (see Appendix).

Summary of logistic regression analysis

In summary, the results of the analyses to find the variables that were able to identify the 10 provinces are shown in Table 1. A total of 29 variables were identified, a high proportion of which related to environmental aspects of shrimp farming. This is an important and interesting finding because it provides strong evidence to support the hypothesis that environmental problems are the cause of reduced productivity and incidence of disease in shrimp farms. In this survey, the initial analysis has shown that the provinces differ significantly in their productivity. The deeper analysis has now identified the key variables that characterise the differences among the provinces. We conclude that some or all of those identified variables are contributing to the variation in farm productivity among the provinces.

Application of GIS to Logistic Regression Analysis

The results of the logistic regression analysis in Table 1 are also shown using GIS in Figures 1 to 4. Any key variable that defined a particular province is indicated by a value = 1 on the column graphs, while a non-significant variable has a value = 0. In Figure 1 there are three key fixed or descriptive variables (i.e. type of soil, number of farming years and sourcs of salt water). In Figure 2 there are 10 key environmental variables: number of farms within 3 km; number of farms sharing water supply; number of farms discharging into water supply; environmental impact assessment; site selection to avoid impact on others; site selection to avoid impact of others; separate water supply/drainage system; retention of mangrove buffer; effluent treatment pond; and other environmental measure.

Table 1. A summary of the key variables that characterise the 10 shrimp farming provinces in Thailand (see text and Appendix for explanation of codes for variables). An asterisk (*) indicates a variable that identifies that province.

Variable	Chanthaburi	Trat	Chumphon	Krabi	Nakhon Sri Thamarat	Phetchaburi	Samut Sakhon	Satun	Songkhla	Surat Thani
SOIL	*		*				*			
Q1_1			*						*	*
Q2_3		*	*						*	*
WSALT						*		*		*
Q6_4		*	*							*
Q7_8	*		*		*			*		
Q7_9					*				*	*
Q7_10	*		*		*			*	*	
Q8_1	*		*		*	*				*
Q8_2		*			*		*	*		*
Q8_3					*				*	
Q8_4	*			*		*			*	
Q8_5			*	*	*	*				
Q8_6		*		*						
Q8_7		*								
Q14PROB		*			*					*
Q14_1B								*		
Q14_2B								*		
Q14_3B										
Q14_10B										*
Q15PROB										
Q15_1D								*		
Q16OTH		*		*				*		*
Q16_2B									*	
Q16_3B								*		
Q16_4B					*				*	
Q16_5B										
Q16_6B			*							
Q16_7B			*							

There are three key problem variables in Figure 3 (i.e. major problem, water or sediment related problem, and other problems). The other nine key variables for problem analysis are shown in Figure 4 and they were: salinity problem; temperature problem; flooding problem; bacteria problem; seed quality; feed quantity; feed quality problem; poaching problem; and power-cut problem.

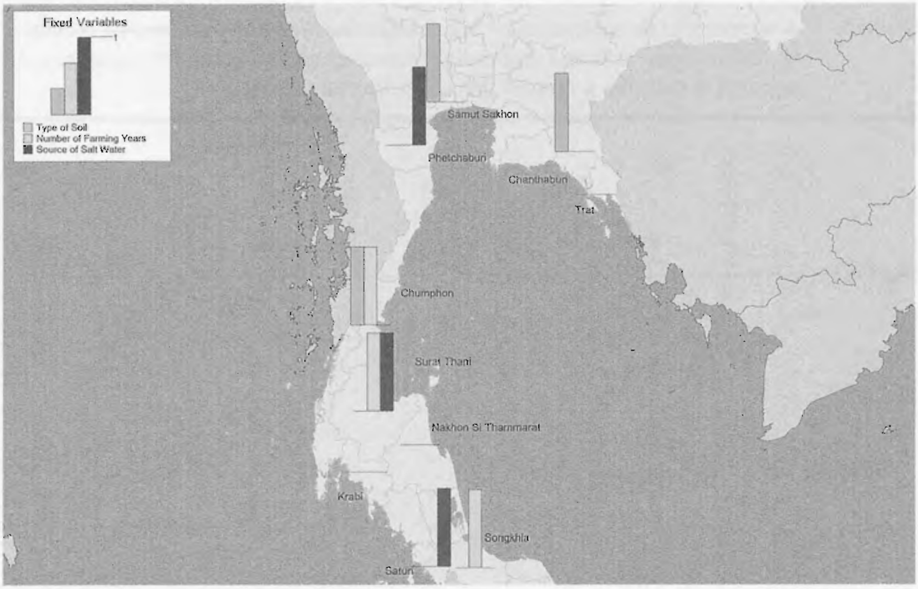

Figure 1. Characterisation of provinces by key fixed variables.

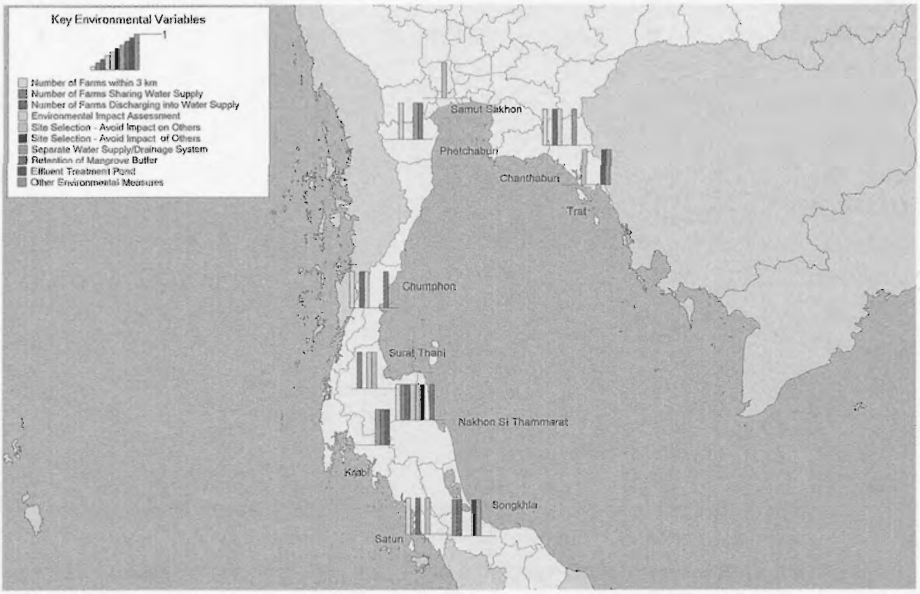

Figure 2. Characterisation of provinces by key environmental variables.

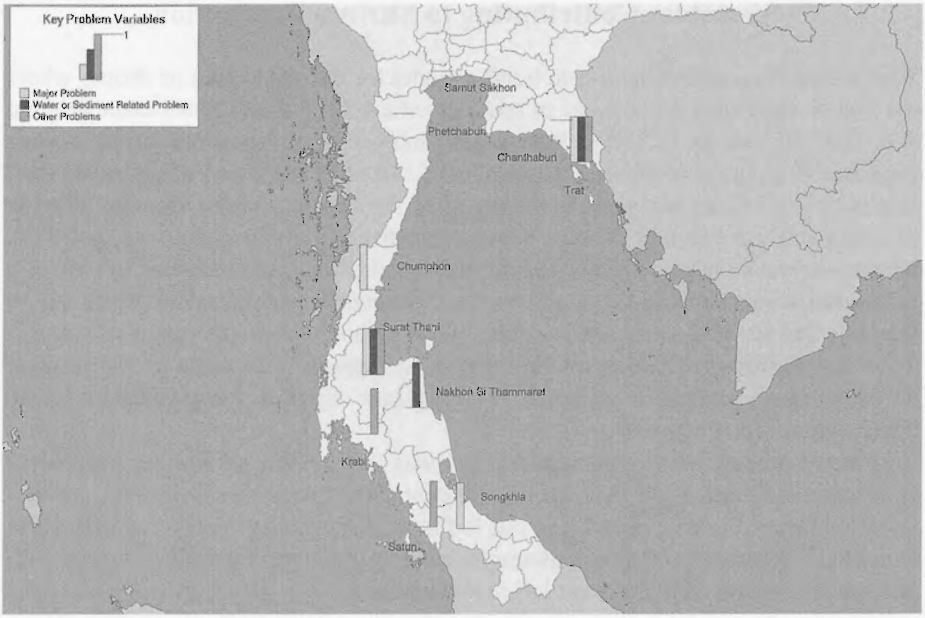

Figure 3. Characterisation of provinces by key problem variables.

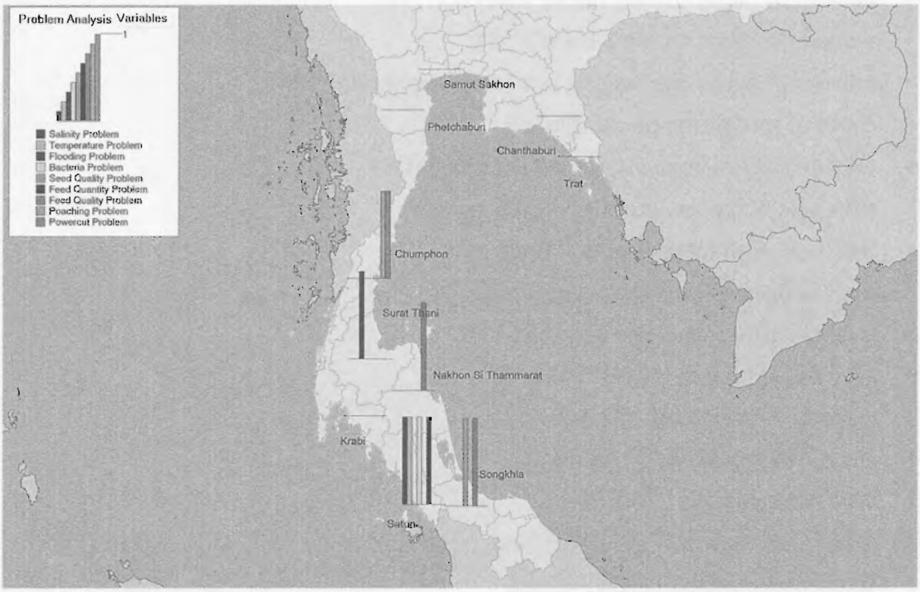

Figure 4. Characterisation of provinces by problem analysis variables.

Variables Contributing to Shrimp Production

This section reports on attempts to build a model for the production of shrimp where the first obstacle was the problem of missing values. In applying SPSS to the original data file, the results indicated that as the number of independent variables was increased to get a better picture, the number of cases left decreased significantly until finally only 27 farms remained in the analysis. For this reason the list-wise deletion of cases was not pursued further. When the substitution of missing values by the means was tried, the value of coefficient of determination (i.e. proportion of variation in the dependent variable explained by the independent variables) decreased due to the reduction in variation of the variables. This method was therefore not acceptable. Then the multiple regression method was used repeatedly to estimate the missing values in the independent variables, resulting in a significant improvement in the coefficient of determination.

Market production of shrimp (kg/ha/yr) was the variable of interest (dependent variable) and all other variables that could contribute to the variation in the production of shrimp were considered. But due to the missing value problem and in order to avoid the violation of underlying assumptions of multiple regression analysis, the following continuous variables were left in the analysis:

- number of years at site (Q1_1 YRFA);
- wet season intake water salinity (ppt) (Q7_6);
- dry season intake salinity (ppt) (Q7_7);
- number of farms sharing intake water (Q7_9);
- number of farms within 3 km (Q7_8);
- number of farms discharging into water supply (Q7_10);
- depth of production ponds (Q6_4);
- total cost of water and sediment problems (Q14_cost);
- total cost of disease problems (Q15_cost);
- total cost of other problems (Q16_cost);
- total estimated fertiliser cost (Q17EFERC);
- total estimated seed cost (Q17ESEED);
- all costs of production (Q17ALCOS);
- estimated power cost (Q17EPOWC);
- estimated feed cost (Q17EFEDC);
- total overheads (Q17TOHD);
- total labour cost (Q17TCLAB); and
- total other input costs (Q17TINC).

Using 200 farms in all 10 provinces with complete information on the variables under consideration, only the following six variables were significant: total overheads (Q17TOHD); total estimated fertiliser cost (Q17EFERC); total labour cost (Q17TCLAB); total feed cost (Q17EFEDC); seed cost (Q17ESEED); and total other input costs (Q17TINC). This method of analysis could explain 75.6% of the total variation in market production of shrimp.

The linear multiple regression model was:

$$Q17KGTOT = -2216.08 + 0.005512*Q17EFEDC + 0.08124*Q17EFERC + 0.03953*Q17ESEED + 0.005279*Q17TCLAB + 0.009421*Q17TINC + 0.004118*Q17TOHD \quad (2)$$

Application of GIS to Modelling Shrimp Production

The relationships between average market production and other variables are shown in Figures 5 to 8. GIS was applied to get a summary picture of some relevant statistical information (Table 2) for the shrimp farms in Thailand, with emphasis on the provinces.

Table 2. Some relevant statistics for shrimp farming provinces in Thailand (figures given are averages for each province).

	Market production (kg/ha/yr)	Feed conversion ratio	Farm area (ha)	Depth of pond (m)	Area of pond (ha)	Size of effluent pond (% of farm)	Depth of effluent pond (m)
Chanthaburi	5,703	1.85	4.75	1.18	2.28	1.32	0.09
Trat	10,122	1.66	2.71	1.84	1.47	5.95	1.57
Chumphon	8,776	2.30	1.94	1.81	1.37	0.43	0.15
Krabi	16,035	1.70	2.15	1.84	1.56	0	0
Nakhon Si Thammarat	8,322	2.04	2.63	1.57	2.02	0.28	0
Phetchaburi	4,622	1.78	3.11	1.50	1.70	0	0
Samut Sakhon	5,662	1.72	2.22	1.36	1.30	6.40	0.03
Satun	11,190	2.25	3.65	1.78	2.14	0.87	0.20
Songkhla	12,067	2.51	1.28	1.51	0.95	0.38	0.03
Surat Thani	8,322	1.92	3.20	1.57	1.64	1.18	0.10

Importantly, analysis of data summarised in Table 2 revealed that (a) there was a positive correlation between depth of ponds and average market production ($P < 0.05\%$); (b) there was a negative correlation between FCR and average market production ($P < 0.01\%$); and (c) there was a negative correlation between the area of production ponds and average market production ($P < 0.05\%$). These correlations were also significant when the province was fixed (i.e. partial correlation—when the analysis was carried out on the variation within each province), however the relationship was not as strong. This is an important observation because it indicates that variability at the farm level becomes obscured when examined at each level above that. That is to say, the relationships that are statistically significant at the lowest unit in this survey (i.e. farm level) are less clear at the second (i.e. province level) and are totally lost at the third level (i.e. four major regions—central, eastern, south-western and

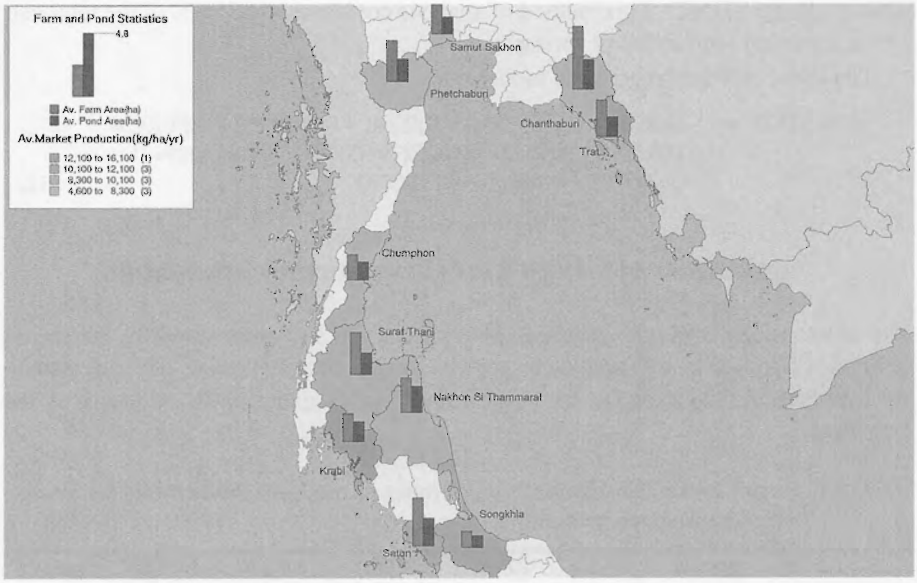

Figure 5. Relationship between average market production and farm and pond area (numbers in brackets = number of provinces in each category).

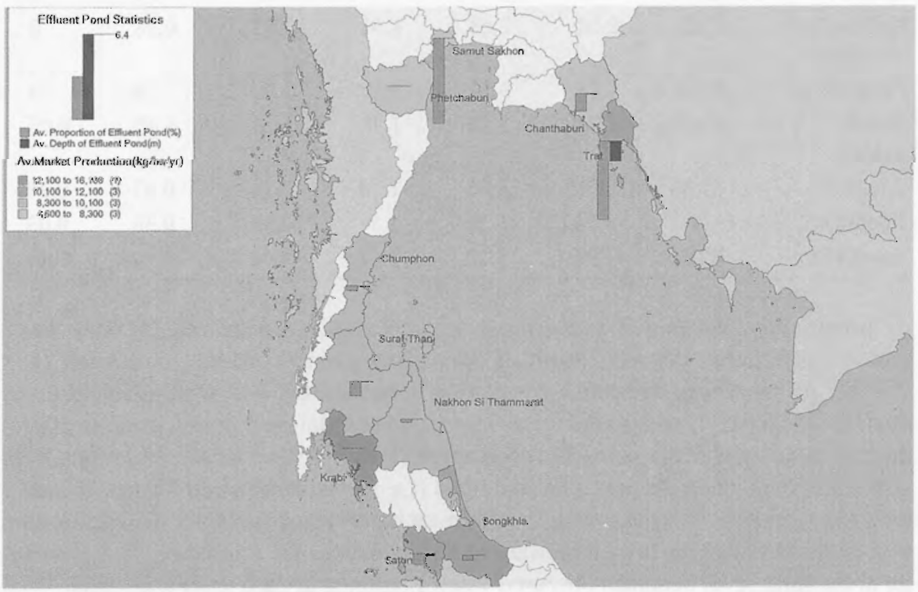

Figure 6. Relationship between average market production and proportion and depth of effluent pond (numbers in brackets = number of provinces in each category).

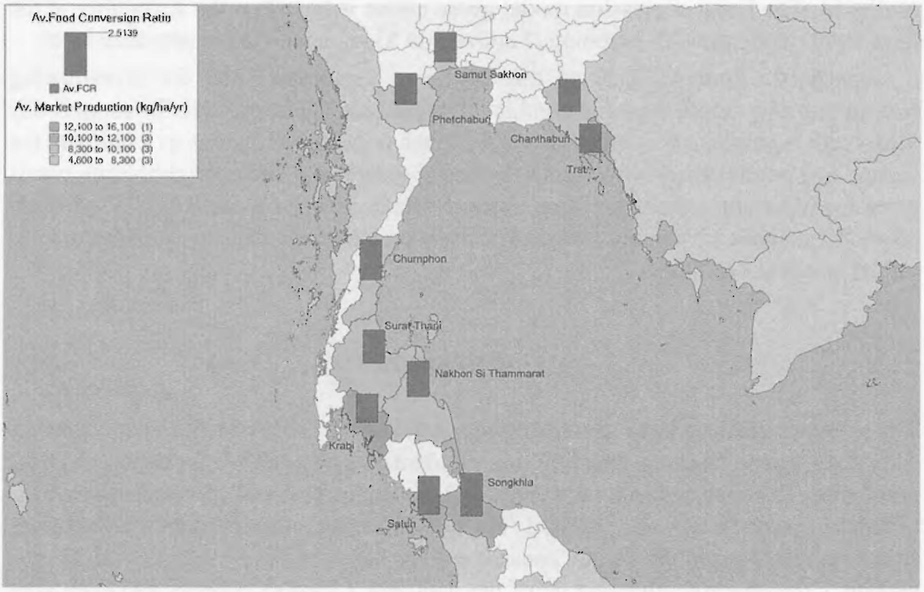

Figure 7. Relationship between average market production and feed conversion ratio (numbers in brackets = number of provinces in each category).

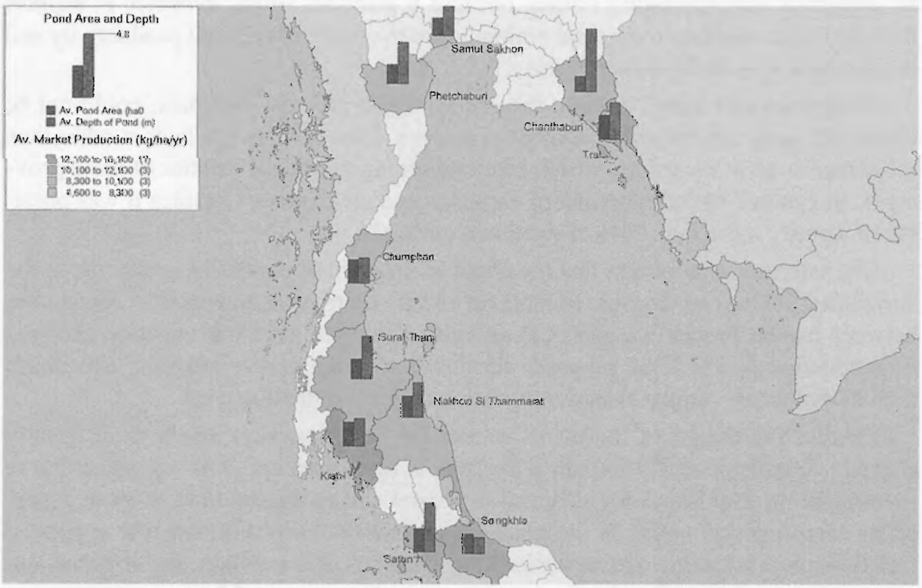

Figure 8. Relationship between average market production and pond area and depth (numbers in brackets = number of provinces in each category).

southern). The linear regression model given above is based on the variability at the farm level, while the GIS mapping (Figures 5 to 8) is viewed at the province level.

Finally, the findings indicate that the most appropriate unit for investigating shrimp farming should be at the pond level rather than the farm level. To support this idea, there is ample anecdotal evidence that each pond at a farm acts as a unit and the shrimp in a pond present with common disease symptoms, while neighbouring ponds often have different characteristics. Hence, future surveys could provide for more powerful analysis by placing greater emphasis on questions that investigate the individual ponds at each farm.

Conclusions

The previous sections have described the results of the analysis of the data from the Thai farm survey from the point of view of identifying the problems prevalent in the provinces. The survey was a very large and ambitious one and consequently a large number of interviewers were needed. The quality of the interviews and the complexity of the questions in the survey became evident when performing data analysis and editing. Consequently, cleaning up of the data was a lengthy process and even after that there was still the problem of missing values in many variables.

Nevertheless, the results of the analysis demonstrated that the average level of production in the 10 provinces was different and due to a few clearly identifiable factors. It was possible to identify eight provinces using a total of 29 key variables, a high proportion of which related to environmental aspects of shrimp farming. This is an important and interesting finding because it provides strong evidence to support the hypothesis that environmental problems are the cause of reduced productivity and incidence of disease in shrimp farms.

Petchaburi and Samut Sakhon Provinces, which are near Bangkok, could not be identified using the variables in other provinces. Hence, there are factors other than those measured in the survey which are determining the characteristics of these provinces. In general, using the problem variables and descriptive variables it was possible to identify more than 90% of the farms correctly.

One interesting point was that the depth of production ponds did contribute to the variability in the production of shrimp. Also, there was a negative correlation between market production and FCR as well as between market production and area of production ponds. This supports the findings of the earlier analysis (see Smith 1999a) that small, family-owned farms are the most productive units.

Finally, the design of the questionnaire for future surveys needs to be greatly altered to enable powerful statistical analysis to be carried out. It is suggested that to investigate the key issues for sustainable coastal shrimp aquaculture, a more appropriate sampling unit could be the pond rather than the farm. Further, it is suggested that field measurements, global positioning system (GPS) readings and environmental samples should be taken by the interviewer in the process of future surveys.

Bibliography

MAPINFO Professional User's Guide 1995. New York, USA, MapInfo Corporation.

MAPINFO Professional Reference 1995. New York, USA, MapInfo Corporation.

Norusis, M.J. 1994. SPSS (Statistical Package for Social Scientists) Professional Statistics 6.1. Chicago, USA, SPSS Inc.

Norusis, M.J. 1994. SPSS (Statistical Package for Social Scientists) Advanced Statistics 6.1. Chicago, USA, SPSS Inc.

Smith, P.T. 1999a. Key issues based on an analysis of data from the Thai shrimp farm survey. In: Smith, P.T., ed., Towards sustainable shrimp culture in Thailand and the region. ACIAR Proceedings No. 90. Canberra, Australian Centre for International Agricultural Research (in press).

Smith, P.T. 1999b. Possible applications of GIS to the Thai shrimp farm survey. In: Smith, P.T., ed., Towards sustainable shrimp culture in Thailand and the region. ACIAR Proceedings No. 90. Canberra, Australian Centre for International Agricultural Research (in press).

Tavarutmaneekul, P. and Tookwinas, S. 1995. Shrimp and carp aquaculture sustainability and the environment: Thailand study report. Regional Study and Workshop on Aquaculture Sustainability and the Environment, Beijing. Network of Aquaculture Centres in Asia–Pacific and the Thai Department of Fisheries, 12p.

Appendix. Results of logistic regression to determine the variables that identify each province

Variable code	Explanation of variable
SOIL	Dominant soil type at the site
Q1_1	Number of years at site
Q2_3	Major problems at the site in the past 3 years
WSALT	Source of salt water to the farm
Q6_4	Total area of production ponds at the farm
Q7_8	Number of aquaculture farms within 3 km of the farm
Q7_9	Number of aquaculture farms which share the water supply
Q7_10	Number of aquaculture farms which discharge effluent into the water supply canal
Q8_1	Environmental impact assessment during the planning design process
Q8_2	Made site selection to avoid impacts on other users
Q8_3	Made site selection to avoid impacts of other users
Q8_4	Design of separate water supply/drainage system
Q8_5	Retention of mangrove buffer zone
Q8_6	Effluent treatment pond
Q8_7	Other measures to reduce impacts of the farm on the environment
Q14PROB	The farm has suffered from a water or sediment related problem
Q14_1B	The number of times that the farm has suffered from salinity problems in 3 years
Q14_2B	The number of times that the farm has suffered from temperature problems in 3 years
Q14_3B	The number of times that the farm has suffered from bioactive chemical problems in 3 years
Q14_10B	The number of times that the farm has suffered from flooding problems in 3 years
Q15PROB	The farm has suffered from a serious disease-related problem
Q15_1D	The number of times in 3 years that the farm has suffered from a serious disease problem
Q16OTH	The farm has suffered from other problems
Q16_2B	The number of times that the farm has suffered from seed quality problems in 3 years
Q16_3B	The number of times that the farm has suffered from feed quantity problems in 3 years
Q16_4B	The number of times that the farm has suffered from feed quality problems in 3 years
Q16_5B	The number of times that the farm has suffered from predation problems in 3 years
Q16_6B	The number of times that the farm has suffered from poaching problems in 3 years
Q16_7B	The number of times that the farm has suffered from powercut problems in 3 years

Key to abbreviations used in the province classifications below:

B	logistic regression coefficients estimated from the data;
S.E.	standard error of the mean;
Wald	Wald's test statistic;
df	degrees of freedom;
R	R statistic showing the partial contribution of individual variables;
Exp(B)	e to the power B (logistic regression coefficient);
–2 log likelihood	–2 times log of likelihood (L) ratio test statistic (measure of how well the estimated model fits the data);
Model Chi-square	the difference between –2 log L for the model with only a constant and –2 log L for the current model; and
Improvement	the change in –2 log L between the successive steps in building a model.

1) Chanthaburi Province

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	249	0	100.00
No	1	9	90.0
			Overall 99.61%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
SOIL	–12.816	124.09	.0108	1	.9171	.0000	.0000
Q8_1	26.4480	1449.40	.0003	1	.9854	.0000	3.06E+11
Q8_4	28.8098	1499.97	.0004	1	.9847	.0000	3.25E+12
Q7_10	27.5447	204.05	.0182	1	.8926	.0000	9.17E+11
Q7_8	–28.1809	204.05	.0191	1	.8902	.0000	.0000
Constant	–11.4136	2082.19	.0000	1	.9956		

–2 log likelihood	5.389
Goodness of fit	5.092

	Chi-square	df	significance
Model Chi-square	79.305	5	0.0000
Improvement	8.94	1	0.0028

2) Trat Province

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	232	4	98.31
No	12	11	47.83
			Overall 93.82%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
Q2_3	1.859	.6309	8.6820	1	.0032	.2074	6.4178
Q8_2	−1.945	.7201	7.2963	1	.0069	−.1847	.1430
Q8_6	2.719	.6972	15.2031	1	.0001	.2916	15.157
Q8_7	2.264	1.1025	4.2163	1	.0400	.1195	9.6206
Q14PRB	1.581	.6657	5.6415	1	.0175	.1531	4.8606
Q16OTH	−2.220	.7265	9.3413	1	.0022	−.2174	.1086
Q6_4 DE	1.984	.8965	4.8970	1	.0269	.1366	7.2710
Constant	−6.831	2.2704	9.0511	1	.0026		

−2 log likelihood	84.157
Goodness of fit	144.102

	Chi-square	df	significance
Model Chi-square	71.119	7	0.0000
Improvement	6.072	1	0.0137

3) Chumphon Province

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	204	1	96.68
No	10	38	79.17
			Overall 93.44%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
Q2_3	–3.0919	.9067	11.6277	1	.0006	–.1969	.0454
SOIL	1.0347	.2697	14.7235	1	.0001	.2264	2.8144
Q8_1	–1.6813	.6062	7.6930	1	.0055	–.1514	.1861
Q8_5	–2.6927	.8610	9.7789	1	.0018	–.1770	.0677
Q7_8	– .1098	.0433	6.4281	1	.0112	–.1335	.8960
Q7_10	.0981	.0405	5.8600	1	.0155	.1247	1.1031
Q1_1YRFA	– .5000	.1839	7.3901	1	.0066	– .1473	.6065
Q16_6B	– 2.7381	.6560	17.4228	1	.0000	.2492	15.4583
Q16_7B	.9749	.7616	1.6387	1	.2005	.0000	2.6509
Q6_4 DEPT	3.2392	.8419	14.8050	1	.0001	.2271	25.5144
Constant	–7.4199	1.9391	14.6417	1	.0001		

–2 log likelihood	107.689
Goodness of fit	459.349

	Chi-square	df	significance
Model Chi-square	140.629	10	0.0000
Improvement	10.110	1	0.0015

4) Krabi Province

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	242	4	98.37
No	7	6	46.15
			Overall 95.75%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
Q8_4	–1.6068	.7307	4.638	1	.0279	–.1658	.2005
Q8_5	10.8247	30.488	.1261	1	.7226	.0000	50249.20
Q8_6	–1.3882	.8531	2.648	1	.1037	–.0793	.2495
Q16OTH	–2.0013	.8874	5.086	1	.0241	–.1730	.1352
Constant	–8.4725	30.507	.0771	1	.7812		

–2 log likelihood	53.874
Goodness of fit	75.690

	Chi-square	df	significance
Model Chi-square	49.252	4	0.0000
Improvement	5.156	1	0.0232

5) Nakhon Sri Thamarat Province

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	223	4	98.24
No	13	19	59.38
			Overall 93.44%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
Q8_1	–1.3920	.6985	3.9708	1	.0463	–.1009	.2486
Q8_2	2.6844	.7290	13.558	1	.0002	.2243	14.6493
Q8_3	2.8305	.7258	15.208	1	.0001	.2611	16.9535
Q8_5	– 2.8311	.8204	11.909	1	.0006	–.2262	.0589
Q7_8	.0448	.0107	17.413	1	.0000	.2821	1.0458
Q7_9	.1031	.0326	9.9988	1	.0016	.2032	1.1086
Q7_10	–.1668	.0386	18.680	1	.0000	–.2934	.8464
Q14PROB	–2.4520	.7788	9.9128	1	.0016	–.2021	.0861
Q16_4B	.6977	.3808	3.3572	1	.0669	.0837	2.0091
Constant	–1.2147	1.0197	1.4189	1	.2336		

–2 log likelihood	89.198
Goodness of fit	179.332

	Chi-square	df	significance
Model Chi-square	104.504	9	0.0000
Improvement	2.899	1	0.0886

6) Phetchaburi Province

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	250	0	100.00
No	9	0	0.00
			Overall 96.53%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
WSALT	–0.5890	.2826	4.3427	1	.0372	–.1731	.5549
Q8_1	–10.3461	55.213	.0352	1	.8511	.0000	.0000
Q8_4	–10.8880	51.868	.0441	1	.8537	.0000	.0000
Q8_6	–10.5500	69.811	.0228	1	.8799	.0000	.0000
Constant	0.6890	0.9305	0.5483	1	0.4590		
–2 log likelihood		38.645					
Goodness of fit		46.898					

	Chi-square	df	significance
Model Chi-square	39.512	4	0.0000
Improvement	5.941	1	0.0148

7) Samut Sakhon Province

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	258	0	100.00
No	1	0	0.00
			Overall 99.61%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
SOIL	1.9329	.9673	3.9927	1	.0457	.3899	6.9094
Q8_1	–10.9592	84.4736	.0168	1	.8968	.0000	.0000
Constant	–13.6361	5.6378	5.8501	1	.0156		
–2 log likelihood		6.446					
Goodness of fit		9.010					

	Chi-square	df	significance
Model Chi-square	6.664	2	0.0357
Improvement	3.559	1	0.0592

8) Satun Province

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	232	3	98.72
No	11	13	54.17
			Overall 94.59%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
WSALT	–.6961	.2070	11.3113	1	.0008	–.2413	.4985
Q8_2	1.4097	.6457	4.7672	1	.0290	.1316	4.0948
Q7_8	–.0473	.0258	3.3584	1	.0669	–.0922	.9538
Q7_10	–.1967	.0978	4.0418	1	.0444	–.1130	1.8214
Q14_1B	.8193	.2395	11.6996	1	.000	.2463	2.2690
Q14_2B	.4682	.2053	5.2018	1	.0226	.1415	1.5971
Q15_1D	.2827	.1113	6.4516	1	.0111	.1669	1.3267
Q16_3B	3.8289	1.804	4.5043	1	.0338	.1252	46.0096
Q16OTH	–1.2009	.6542	3.3694	1	.0664	–.0925	.3009
Constant	.8195	1.1942	.4709	1	.4926		
–2 log likelihood		78.867					
Goodness of fit		131.376					

	Chi-square	df	significance
Model Chi-square	81.018	9	0.0000
Improvement	5.185	1	0.0228

9) Songkhla Province

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	199	4	98.03
No	16	40	71.43
			Overall 92.28%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
Q1_1YRFR	.1878	0406	21.350	1	.0000	.2675	1.2066
Q2_3	–1.8996	.7177	6.9824	1	.0082	–.1357	.1501
Q8_3	–1.9457	.8275	5.5293	1	.0187	–.1142	.1429
Q8_4	–2.1239	.6511	10.631	1	.0011	–.1786	.1197
Q7_9	–.2640	.0650	16.489	1	.0000	–.2315	.7680
Q7_10	.2716	.0648	17.553	1	.0000	.2398	1.3120
Q16_2B	–2.0181	.7305	7.6316	1	.0057	–.1443	.1329
Q16_4B	–5.4565	10.601	.2649	1	6067	.0000	.0043
Constant	–1.3816	.3768	13.443	1	.0002		
–2 log likelihood		103.202					
Goodness of fit		177.639					

	Chi-square	df	significance
Model Chi-square	167.234	8	0.0000
Improvement	12.568	1	0.0004

10) Surat Thani Provinc

Classification table

	Predicted		
Observed	Yes	No	% correct
Yes	206	10	95.37
No	17	26	60.47
			Overall 89.58%

Variables in the equation

Variable	B	S.E.	Wald	df	Significance	R	Exp(B)
WSALT	.3418	.1413	5.8549	1	.0155	.1287	1.4075
Q1_1YRFR	–.1971	.0788	6.2508	1	.0124	–.1351	.8211
Q2_3	1.4143	.5181	7.4526	1	.0063	.1530	4.1136
Q6_4DEPT	–2.350	.7247	10.5176	1	.0012	–.1913	.0953
Q8_1	2.2671	.5266	18.5357	1	.0000	.2655	9.6509
Q8_2	– 2.233	.6037	13.6870	1	.0002	–.2240	.1072
Q7_9	.0212	.0087	5.8834	1	.0153	.1291	1.0214
Q14PROB	.5691	.5037	1.2764	1	.2586	.0000	1.7667
Q14_10B	.9705	.5143	3.5607	1	.0592	.0819	2.6393
Q16OTH	2.5014	.7443	11.2960	1	.0008	.1998	12.1999

Variables in the equation

Constant	–5.179	2.046	6.4058	1	.0114
–2 log likelihood		125.594			
Goodness of fit		153.288			

	Chi-square	df	significance
Model Chi-square	107.260	10	0.0000
Improvement	6.277	1	0.0122

Priorities for Shrimp Research in Thailand and the Region

Paul T. Smith* and Michael J. Phillips†

Abstract

This chapter reports on the results of the discussion sessions that were held at the project's Workshop in Hat Yai, Songkhla, October 1996, as well as the findings of a Post-Workshop Survey of participants. A total of 49 participants from 12 countries were present at the Workshop, while 25 participants from 6 countries responded to the survey. Researchable issues were identified in eight areas: disease and health; environmental impact assessment and monitoring; feed and nutrition; genetics and broodstock; farm and pond management; remediation of disused farms and damaged habitats; socioeconomics, trade and licensing; and information transfer and training. The two most important areas for research were disease and health, and farm and pond management. Participants considered that the three greatest constraints to sustainability in their own countries were viral diseases, poor pond management, and self-pollution. The same constraints were identified for the Asia-Pacific region, suggesting that there is good scope for intra-regional research projects and linkages with related projects. A total of 122 researchable issues were identified by the participants and the features of the issues were characterised in terms of: impact on productivity; achievability; importance; ongoing research; target of research; and a ranking for the priority of the research. The priority for each researchable issue was determined by scoring each issue on a scale from lowest priority = 1 to highest priority = 10. Eleven issues received the highest priority, with a median score of ≥8. These issues were from five of the eight areas of research and they received broad support from participants across the Asia–Pacific region. In the ranking process, genetics and broodstock was the area which participants gave most support, with 79% of its issues receiving a median score of ≥6. Additional comments by participants in the survey suggested that some of the issues were related and could be combined in research projects.

Background

The research issues identified at the project's Workshop held at Hat Yai, Thailand in 1996, have been previously summarised (Smith et al. 1996; Anon. 1997), however the ranking of issues by the experts at the Workshop has not previously been reported. This chapter details the findings of two methods which were used to rank issues: (a) consensus opinions obtained at the Workshop during discussion sessions in October 1996 and (b) a Post-Workshop Survey of all participants in September–October 1997.

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A total of 49 participants were involved in the Workshop and most of them described themselves as either researchers (n = 27) or fisheries officers (n = 10). Other groups represented in the process included shrimp farmers (n = 2), consultants (n = 4) and executive officers of government. Participants were mainly from Thailand (n = 30) and Australia (n = 8), though China, India, Indonesia, Malaysia, the Philippines, Sri Lanka, Vietnam, Bangladesh, Denmark and the United Kingdom were represented.

A total of 25 participants from 6 countries completed the Post-Workshop Survey. Most participants were from Thailand (16) and Australia (5), while the rest were from China, Sri Lanka, the Philippines and Malaysia. The average period of involvement with shrimp farming by participants who completed the survey was 10.2 years (range of 1 to 23 years).

Perceived Constraints to Sustainability and Preferred Weighting for Research Funding

Participants were surveyed to determine the overall weighting that should be given to the main areas of research funding. The results are shown in Table 1 and Figure 1. The most important areas were: disease and health, and farm and pond management, followed by genetics and broodstock, and feed and nutrition. The least important areas were: socioeconomics, trade and licensing; and remediation of disused farms. A comment by one participant was that efforts to bring disused farms into production could exacerbate problems with achieving sustainability.

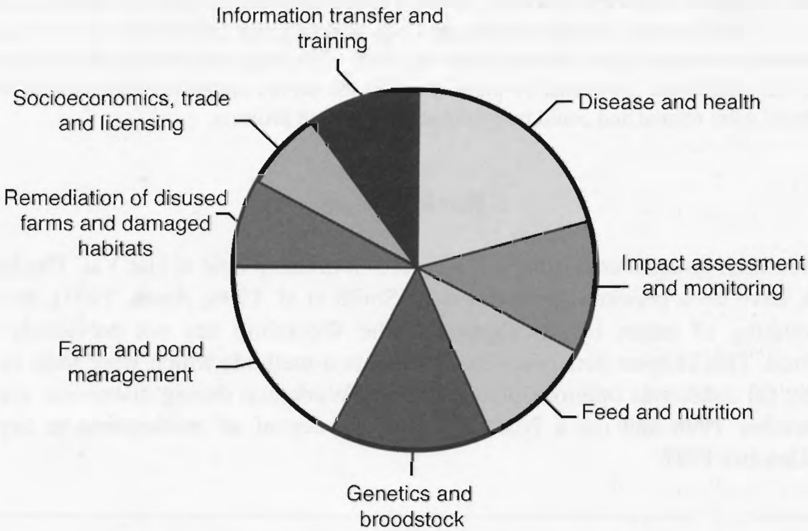

Figure 1. The average weighting which should be given for research funding, as considered by survey participants.

Table 1. The preferred weighting for research funding. Points were allocated to each research area according to its importance in improving the sustainablity of shrimp farming. Each participant allocated a total of 100 points. Results show mean ± standard deviation (minimum–maximum).

Research area	Weighting
Disease and health	20.6 ± 7.5 (10–40)
Environmental impact assessment and monitoring	11.8 ± 5.7 (5–20)
Feed and nutrition	11.1 ± 6.5 (0–30)
Genetics and broodstock	14.3 ± 7.1 (5–30)
Farm and pond management	17.7 ± 9.7 (5–40)
Remediate disused farms and damaged habitats	7.6 ± 5.6 (0–25)
Socioeconomics, trade and licensing	7.2 ± 5.5 (0–25)
Information transfer and training	9.9 ± 3.5 (5–20)

Participants considered that the three greatest constraints to sustainability in their country were viral diseases, poor pond management and self-pollution (Table 2) and were the same constraints that participants identified for the Asia–Pacific region (Table 3). The three least important constraints to sustainability in their own country were identified as trade restrictions, poor infrastructure and market competition (Table 2). In comparison, the least important constraints for Asia–Pacific were impact of civilisation, trad restrictions and market competition (Table 3).

Table 2. Factors which were considered to be the most important constraints to sustainability of the shrimp industry in **the participant's country**. Points were allocated to each research area according to its importance in improving the sustainability of shrimp farming. Each participant allocated a total of 100 points. Results show mean ± standard deviation (minimum–maximum)

Constraint	Points allocation
Viral disease	14.1 ± 8.7 (2–40)
Bacterial disease	7.3 ± 5.9 (0–25)
Self-pollution	10.2 ± 7.1 (0–30)
Impact of civilisation	3.6 ± 3.4 (0–15)
Hatchery problems	6.7 ± 5.7 (0–20)
Broodstock problems	7.5 ± 5.1 (0–20)
Lack of training	6.2 ± 6.1 (0–20)
Trade restrictions	2.0 ± 3.2 (0–10)
Government regulations	5.6 ± 4.2 (0–13)
Poor pond management	12.4 ± 8.2 (0–30)
Feed problems	5.3 ± 5.1 (0–20)
Degrading of ponds with time	8.8 ± 6.1 (0–20)
Conflicts over land use	4.1 ± 5.7 (0–25)
Poor infrastructure	2.2 ± 2.8 (0–10)
Market competition	1.1 ± 1.9 (0–6)
Lack of appropriate research	7.7 ± 6.0 (0–23)

Figure 2 shows the levels of constraints to issues of sustainable shrimp farming in the participant's own country and the Asia–Pacific region. The similarity between the levels in the participant's own country and Asia–Pacific suggests there is good scope for cooperation in research within the region. Common problems could be addressed by developing intra-regional research projects and linkages with related projects.

Table 3. Factors which were considered to be the most important constraints to sustainability of the shrimp industry in the **Asia–Pacific** region. Points were allocated to each research area according to its importance in improving the sustainablity of shrimp farming. Each participant allocated a total of 100 points. Results show mean ± standard deviation (minimum–maximum).

Constraint	Points allocation
Viral disease	13.4 ± 5.4 (2–25)
Bacterial disease	8.6 ± 4.9 (0–20)
Self-pollution	10.6 ± 7.0 (0–30)
Impact of civilisation	2.8 ± 3.4 (0–10)
Hatchery problems	7.4 ± 6.2 (0–30)
Broodstock problems	7.3 ± 4.9 (0–20)
Lack of training	5.0 ± 5.3 (0–20)
Trade restrictions	2.9 ± 3.7 (0–10)
Government regulations	5.9 ± 3.7 (0–10)
Poor pond management	11.3 ± 6.1 (0–20)
Feed problems	4.7 ± 5.0 (0–20)
Degrading of ponds with time	8.3 ± 5.3 (0–20)
Conflicts over land use	4.4 ± 4.1 (0–15)
Poor infrastructure	4.4 ± 3.9 (0–14)
Market competition	1.4 ± 2.4 (0–9)
Lack of appropriate research	6.8 ± 7.5 (0–30)

Results of Workshop Discussions and the Post-Workshop Survey

Eight major areas of research were identified at the Workshop and each area was subdivided into a total of 122 researchable issues (see Appendices 1 to 8). These issues were concisely written by sub-groups and consensus views were obtained during discussion sessions that were held during and after the Workshop. In particular, each issue was categorised according to five factors: the impact on productivity; achievability; importance; ongoing research efforts; and application of the research to target groups. In the Post-Workshop Survey, participants were asked to score each issue on a scale of 1 to 10 (lowest to highest, respectively) to indicate the priority of the research with respect to developing a sustainable shrimp industry. Each score could be used a maximum of 15 times.

For each of the 122 issues, summary statistics were calculated for the scoring. The mean, standard deviation and median are listed in the tables in the Appendices. Figure 3 shows that there were 11 issues that received a median score of 8 out of 10 by the participants. These 11 issues also received broad support from participants from across the Asia–Pacific region. Table 4 shows that for the six countries represented in the survey, the median score was ≥8 for those 11 issues in three to five of the countries represented. Hence, these issues would be highly suitable for cooperative research projects. Figure 3 also shows that there were 31 issues that received a median score of 7, and 20 issues had a median score of 6.

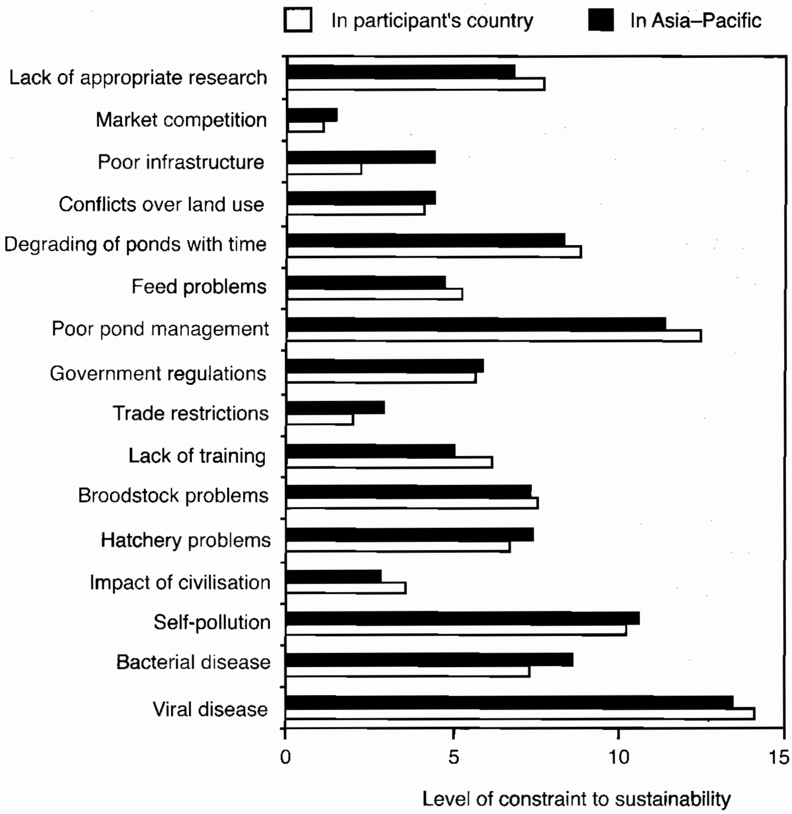

Figure 2. The levels of constraints to sustainable shrimp aquaculture as derived from survey responses.

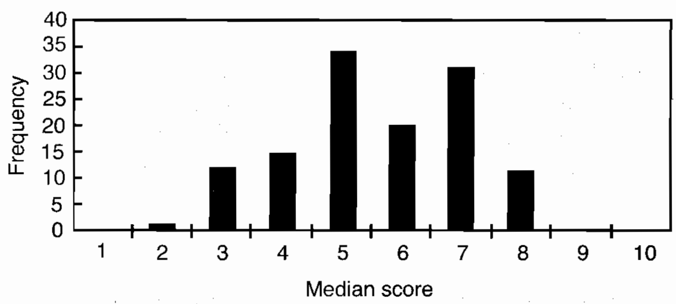

Figure 3. The frequency of median scores for all of the 122 researchable issues.

All issues are listed in Appendices 1 to 8 and they are briefly discussed in the following sections. The columns in the Appendices characterise each issue according to six features (see caption to Appendix 1). This characterisation will assist researchers, institutions and fisheries managers to assess the value that can be obtained from projects which address these issues.

Table 4. The researchable issues that received the highest priority for research by the participants in the Post-Workshop Survey. All of these issues received a median score of 8 out of 10.

Issue No.	Researchable issue	Area of research	**Countries giving median scores ≥8**
7	Develop high health–low risk pond management methods	Disease and health	Thailand, Australia, Philippines
16	Develop practical methods of immuno-prophylaxis for shrimp	Disease and health	Thailand, Australia, Philippines, China
30	Interactions between nutrition and shrimp health	Disease and health	Thailand, Australia, Philippines, China
32	Assess causes of water quality deterioration	Environmental impact assessment and monitoring	Thailand, Australia, Philippines, China
34	Effluent management and waste treatment technologies	Environmental impact assessment and monitoring	Thailand, Australia, Philippines, Sri Lanka
67	Endocrinology of broodstock maturation	Genetics and broodstock	Thailand, Australia, Philippines, China
69	Develop techniques for sustainable broodstock supply, preferably with domesticated broodstock	Genetics and broodstock	Thailand, Australia, Philippines, China, Malaysia
77	Develop high health hatchery production methods	Genetics and broodstock	Thailand, Australia, China
81	Study pond dynamics and pond ecology	Farm and pond management	Thailand, Australia, Philippines, China, Malaysia
82	Better control of pond environment through biological agents and microbial ecology	Farm and pond management	Thailand, Australia, Philippines, China, Malaysia
120	Develop cost-effective training and technology transfer methods and approaches to overcome inadequacies in transfer of information from research to farm	Information transfer and training	Thailand, Australia, Philippines, China, Malaysia

Disease and health

Appendix 1 lists the 31 issues and the descriptive statistics for issues in the area of disease and health. The overall trends in the descriptive statistics suggest that this area was a high priority for research, with a total of 19 of the 31 issues (i.e. 61%) scoring a median score of ≥6 out of 10 (Figure 4). In addition, the scores for impact on productivity were relatively high, with 18 research issues receiving more than average scores. With respect to the score for achievability, most issues were classified as short to medium term, with only two issues being scored as long-term and three issues as medium to long term. The scores for importance were mainly either adaptive or strategic, with only eight issues being described as tactical. Ongoing research was scored as limited, with 19 issues having some or very little ongoing research. The application of the research was generally targeted at the whole Asia–Pacific region, for semi-intensive and intensive systems, and for all scales of farming. Interestingly, five issues had application to the fishing industry either by determining the extent of disease in wild stocks (issue 13), determining modes of transmission of viral disease (issue 14), impacts of toxicants (issues 20 and 29), or managing disease in order to reduce the spread of disease to the wild (issue 1).

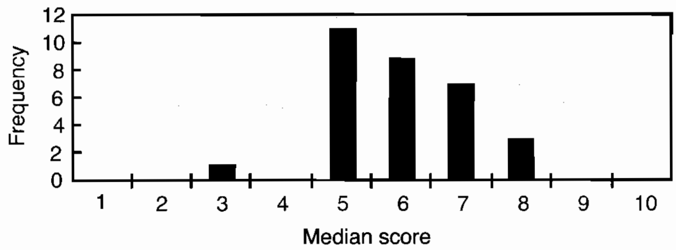

Figure 4. The frequency of median scores for issues in the area of disease and health.

However, the four issues with highest ranking (i.e. mean score >7) had scores which varied to some extent from the norm. The four issues were: development of high health–low risk pond management methods (issue 7); interactions between nutrition and shrimp health (issue 30); studies on biological control of disease in hatchery and farms including vertical transmission of disease in broodstock (issue 31); and development of practical methods of immunoprophylaxis for shrimp (issue 16). These issues varied from other issues in that (a) all four were given the maximum score for impact on productivity, and (b) the time frame for achievability was medium to long rather than short term.

Also, one participant commented in their completed survey that issues 2, 7, 9 and 11 (see Appendix 1) were similar and may be incorporated in a single research study.

Environmental impact assessment and monitoring

The general trends in the scores for the 22 research issues in the area of environmental impact assessment and monitoring are shown in Appendix 2. Overall, 9 of the 22 issues (i.e. 44%) had a median score of ≥6 out of 10 (Figure 5). With respect to impacts on productivity, scores ranged fairly evenly from high to low. The time frame for achievability was generally either medium to long term; only two issues were short term and one issue was short to medium term. As for importance, most issues were scored as strategic and/or adaptive, with only six issues having a tactical importance. The ongoing research effort was generally scored as very low, with 15 issues having the lowest possible score. The application of research was very broad; all issues had application to the Asia–Pacific region, and to semi-intensive and intensive systems. Interestingly, the research was rated as having benefits for a large group of people, with the community and fishing groups being targets for 16 of the issues.

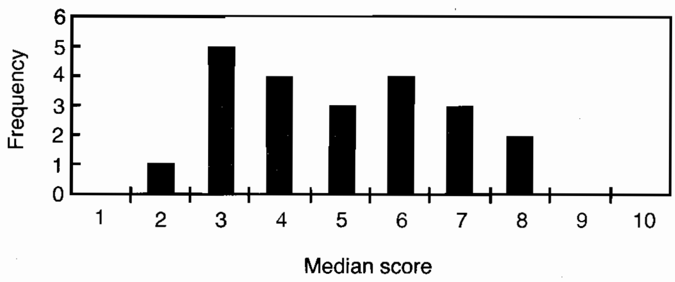

Figure 5. The frequency of median scores for issues in the area of environmental impact assessment and monitoring.

The four issues with the highest ranking (i.e. mean score ≥6.8) were: assessment of causes of water quality deterioration (issue 32); effluent management and waste treatment technologies (issue 34); reduction of pollutant loads through development of low pollution feeds (issue 35); and integrated participatory approach to improve shrimp wastewater management (issue 53). These issues were considered to have the highest impacts on productivity, to be achievable in the medium to long term, and to be mainly of strategic and tactical importance. In keeping with the overall trends, the ongoing research for these four issues was very low, and the application of the research was to broad socioeconomic groups, including the fishing industry and the community.

Further, one participant commented that issues 34 and 53 could be incorporated into one research project, and issues 46, 48, 50 and 52 (see Appendix 2) were on a similar theme and could be combined in one research project.

Feed and nutrition

The statistics for the 13 issues identified in the area of feed and nutrition are shown in Appendix 3. The overall trends show that only 4 of the 13 issues (i.e. 31%) had a median score of ≥6 out of 10 (Figure 6). Also, the issues had a relatively modest score for impact on productivity, with only seven issues scoring greater than average. Issues were achievable in either a short or medium term; no issues were rated as long term. The issues were either adaptive and/or strategic, with no issues identified as tactical. Ongoing research efforts were relatively low, with 10 of the issues having had little or very little research efforts. The targets of the research were generally the Asia–Pacific region, semi-intensive and intensive systems, and all scales of farms. The exception was issue 5 (use of local raw materials), which was of benefit only to some countries. Other exceptions were issues which had application to either the fishing industry or the community and these exceptions were: studies to reduce feed conversion ratio (FCR) (issue 55); removing shrimp by-products or marine protein from feed (issues 57 and 63); and reducing the impact of feed on the environment (issue 64).

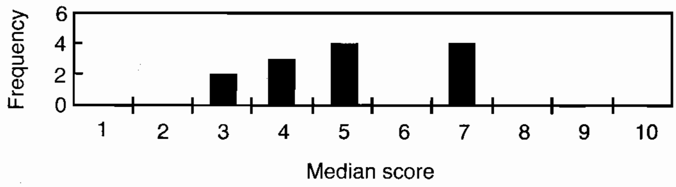

Figure 6. The frequency of median scores for issues in the area of feed and nutrition.

The four most highly ranked issues (i.e. scoring ≥6.4) were: reducing FCR (issue 55); feed management strategies (issue 54); improved protein digestibility and utilisation of animal/marine protein (issue 63); and strategies to reduce impact of feed on the environment (issue 64). These four issues all received a high rating for impact of feed on productivity and were mainly achievable in the medium term. Issues 54 and 55 have received a relatively high level of ongoing research while issues 63 and 64 have had less research effort. Except for issue 54, these issues had impacts on the fishing industry and the community.

Also, one participant commented that issues 54, 55 and 64 were related and could be combined in a research project, and that issues 34, 35 and 53 (see Appendix 3) could also be investigated in the same project.

Genetics and broodstock

The statistics for the 14 issues in the area of genetics and broodstock (Appendix 4) reveal there are gaps in research which have the potential for large benefits to the industry. Overall, a total of 11 of the 14 issues (i.e. 79%) had a median score of ≥6 out of 10 (Figure 7), a level which identified this area of research as receiving the highest support by participants. Also, the impacts on productivity were rated as relatively very high, with ten issues scoring above average impacts. Achievability ranged from short to long term; eight issues were long term, or long to medium term, while five issues were short or short to medium term. The importance ranged equally between strategic, adaptive and tactical. Ongoing research was relatively poor, with eight issues scoring the lowest score and the remaining issues scoring average or less than average ongoing effort. The application of the research was to the Asia–Pacific region, all systems and all scales of farms. Importantly, six issues also had the fishing industry as the target group, principally by reducing the need to use wild broodstock or by learning more about wild populations. One issue also had importance for research effort by providing healthy stocks for disease research (issue 79).

The four issues with highest priority (mean score ≥7.3) were: development of high health hatchery production methods (issue 77); the study of endocrinology of broodstock maturation (issue 67); development of techniques for sustainable broodstock supply (issue 69); and increasing fecundity and nauplius production from pond-reared broodstock (issue 71). They all had a high score for impact on productivity; three issues receiving a maximum score. Achievability ranged from short through to long term and research was mainly strategic. The ongoing research was relatively low, and the application of the research was similar to the overall trend.

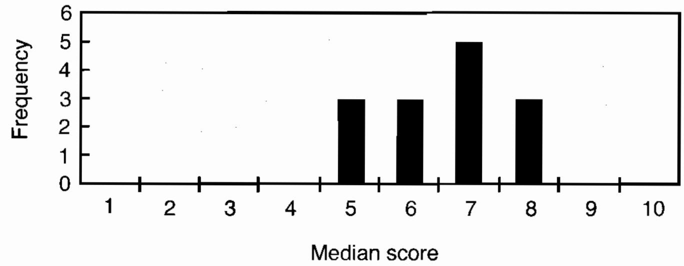

Figure 7. The frequency of median scores for issues in the area of genetics and broodstock.

Three participants commented that issues in this area were related and could be combined in research projects. In particular, one project could incorporate issues 67, 69, 70 and 71, while another project could combine issues 74, 75, 78 and 79 (see Appendix 4).

Farm and pond management

Appendix 5 shows the statistics for the 15 issues in the area of farm and pond management. A total of 10 of the 15 issues (i.e. 67%) had a median score of ≥6 out of 10 (Figure 8). This area scored relatively highly for impact on productivity, with five issues scoring average, and of the remaining ten issues, six received a maximum score. Achievability was generally medium term while the importance was scored between adaptive, strategic and tactical. Ongoing research was relatively low, with eight issues scoring average effort, and the remainder below average. Most issues were applicable to the Asia–Pacific region, but two issues had application to only some countries (i.e. issue 94—development of polyculture, and issue 95—integration of alternative species).

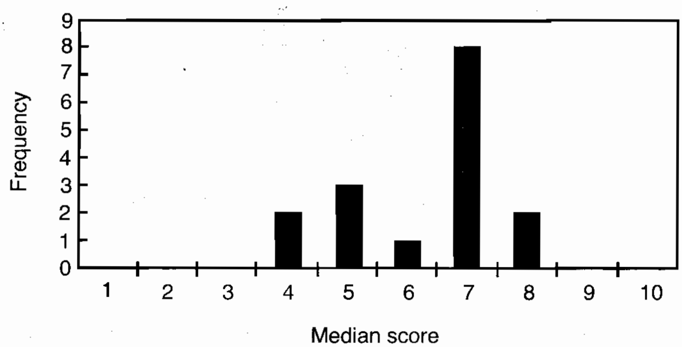

Figure 8. The frequency of median scores for issues in the area of farm and pond management.

The four issues which ranked highest (i.e. mean score ≥7.5) were: studies in pond dynamics and pond ecology (issue 81); improved application of existing technologies from other disciplines (issue 86); development of cost-effective closed water systems (issue 90); and identification and control of factors important in plankton blooms (issue 91). These issues had very high scores for impact on productivity. They were mainly achievable in the medium term, except for issue 86, which was short to medium term, and issue 91, which was medium to long term. Ongoing research was reasonable, except for issue 86 which had low efforts. The targets for the research were similar to the general trend except for issue 90 which was important for small farms.

Two participants commented that issues 81, 82, 86, 87 and 91 were related and could be combined in one research project, and that issues 94 and 95 (see Appendix 5) could be investigated in another project.

Remediation of farms and habitats

The statistics for the 17 issues in the area of remediation of farms and habitats are shown in Appendix 6. Overall, 3 of the 17 issues (i.e. 43%) had a median score of ≥6 out of 10 (Figure 9). The impact on productivity was scored very highly, with two issues scoring average and the remainder above average. Most issues were rated as short or medium term, with only mangrove rehabilitation being a long-term issue. The importance was either adaptive or strategic. The ongoing research was relatively low, with one issue receiving average effort. The target of the research was mainly the region, semi-intensive and intensive systems, and all scales of farms. The notable exceptions were issues where the community and/or fishing industry received benefits (i.e. issues 96, 99 and 102—see Appendix 6). Notwithstanding these scores, the overall priority for this area of research was relatively low.

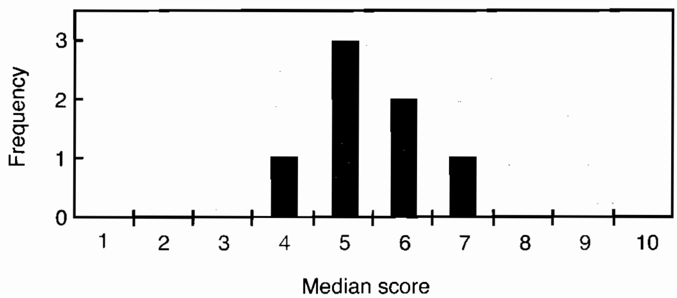

Figure 9. The frequency of median scores for issues in the area of remediation of farms and habitats.

The three issues with highest priority (mean ≥6.1) were: mangrove rehabilitation (issue 102); assessment of technologies for pond rehabilitation (issue 101); and rehabilitation case studies in abandoned ponds (issue 99). Although these issues were scored as having a relatively high impact in spite of the low ranking, the ongoing research effort score was relatively low, suggesting there was room for research.

Two participants commented that issues 96, 97 and 98 were related and could be combined in one research project, and that issues 99 and 101 (see Appendix 6) could be investigated in another project.

Socioeconomics, trade and licences

The statistics for the 10 issues in the area of socioeconomics, trade and licenses are shown in Appendix 7. None of the 10 issues had a median score of ≥6 out of 10 (Figure 10), so this area received lowest support from the participants. However, the standard deviation for these issues was generally higher than for any other area. This suggests there was a greater degree of polarisation of opinions on the priority of these issues. In general, the achievability of issues were short to medium term, with only two issues (issues 103 and 112) rating as medium to long term. The issues were mainly tactical and/or adaptive. The overall ongoing research effort was rated as relatively very low, with six issues scoring the lowest score. The targets of the research were generally the Asia–Pacific region, all systems, and all scale of farms. Importantly, the community was a target for all ten issues, which makes this area unique among the eight research areas.

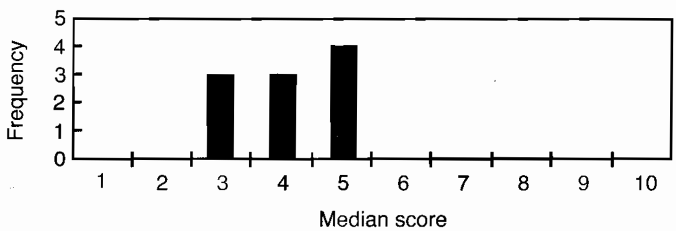

Figure 10. The frequency of median scores for issues in the area of socioeconomics, trade and licenses.

As mentioned, the scoring for the 10 issues in this area were quite low, with only one issue scoring of >6.0, i.e. issue 105 (factors determining profitability of farms with respect to disease control and water treatment). Further, one participant commented that issues 41 and 105 were related and could be combined in a research project, and that issues 106 and 107 (see Appendix 7) could be investigated in another project. Further, issue 111 could be investigated in combination with issue 46, and issue 50 could be combined with research into issue 112. The approach of combining the issues in this area with research projects in other areas may be an appropriate method of establishing linkages between diverse research disciplines.

Information transfer and training

The descriptive statistics for the 10 issues in the area of information transfer and training are shown in Appendix 8. A total of 5 of the 10 issues (i.e. 50%) had a median score of ≥6 out of 10 (Figure 11). One participant commented that issues 115 and 48 were related and could be combined in one research project, and that issues 117, 118, 119 and 120 (see Appendix 8) could be investigated in another project. Further, some respondents to the survey commented that this area may not be considered an area of research at all, however at the October 1996 Workshop (see Smith 1999), the general feeling was that this area did have a research component.

Overall, the impacts on productivity were scored relatively well, with four issues scoring above average. Achievability was rated as short to medium term for most issues, with only three issues rated as medium to long term (issues 115, 116 and 122). The importance was generally rated as either adaptive or tactical with only three issues rated as strategic. The ongoing research effort was rated as below average in 8 of the 10 issues. The targets for the research were generally listed as the Asia–Pacific region, all systems, and all farms. Importantly, seven issues also had application to the community.

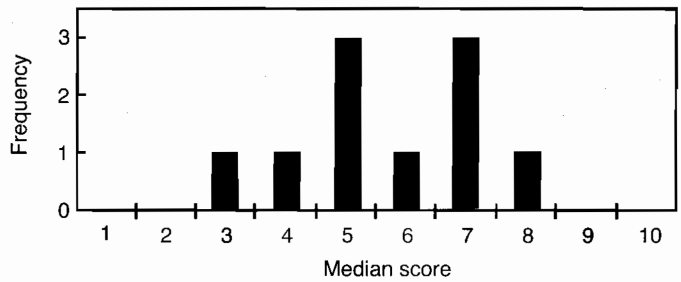

Figure 11. The frequency of median scores for issues in the area of information transfer and training.

The three issues with highest priority (i.e. mean score ≥7.0) were: research information extension services and education of farmers (issue 116); development of cost-effective training and technology transfer methods (issue 120); and improving farmer awareness of downstream environmental impacts (issue 119). These issues were rated to have a high impact on productivity and were generally medium-term projects. Ongoing research was rated as reasonable, and all three have the community as one of the target groups for the research.

Conclusions

1. The Workshop discussion sessions and the survey of participants have provided a list of researchable issues that have been categorised according to a range of practical criteria. Importantly, it was possible to rank 122 research issues in terms of their importance to developing a sustainable shrimp industry.
2. In the ranking process, research into genetics and broodstock was the area which participants gave most support, with 79% of issues receiving a median score of ≥6 out of 10. However, in the preferred weightings for each area of research, two other areas (i.e. disease and health, and farm and pond management) received higher weightings (Table 1).
3. Research issues which received the highest ranking (Table 4) were spread between a range of areas: disease and health; environmental impact assessment and monitoring; genetics and broodstock; farm and pond management; and infor-

mation transfer and training. This may reflect the diversity of the problems that confront the shrimp farming industry.

4. Additional comments by participants suggested that some of the issues were related and could be combined in research projects. This research could be carried out more effectively if research groups within the Asia–Pacific region increased their collaboration. The advantages of linking projects in collaborative studies would be:

- better exchange of data between groups during regular joint project workshops;
- application of powerful statistics to pooled databases;
- increased efficiency in data collection by exchange of equipment and researchers; and
- rapid communication of results between the collaborating groups.

The results presented in this study provide a framework by which linkages could be developed.

References

Anon. 1997. Year-end meets tackle issues on shrimp culture and reef fishes. Bangkok, NACA (Network of Aquaculture Centres in Asia–Pacific) Newsletter, Vol. XIII, No. 4, 1–3.

Smith, B., Lal, P. and Willet, I. 1996. Shrimp farming in coastal environments. Briefing Paper for the Australian Centre for International Agricultural Research (ACIAR) Policy Advisory Council Meeting (PAC 17), Canberra, December 1996, 15p.

Smith, P.T. (ed.) 1999. Towards sustainable shrimp culture in Thailand and the region. ACIAR Proceedings No. 90. Canberra, Australian Centre for International Agricultural Research (in press).

Appendix 1. Descriptive statistics for research issues in the area of disease and health.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
1	Application of existing veterinary health management strategies to shrimp	+++++	medium	adaptive	++	region all systems farms and fishing	6.4 ± 2.8 (7)
2	Assessment of high risk activities in current shrimp aquaculture systems (chain of production and marketing)	++	short	strategic	++	some countries all systems all farms	5.8 ± 2.8 (6)
3	Carry out case studies of previous disease outbreaks	+	short	adaptive and tactical	+++	region all systems all farms	4.8 ± 2.1 (5)
4	Cost–benefit analysis of disease control practices	++	short	strategic and tactical	++	region s.i. and i. systems all farms	5.2 ± 2.1 (5)
5	Development of generic response strategies for different types of infection	++++	short	strategic	+++	region s.i. and i. systems all farms	5.2 ± 2.3 (5)
6	Development of farm designs incorporating best disease control features	++++	long	strategic and adaptive	+	region s.i. and i. systems big farms	6.8 ± 2.3 (7)
7	Development of high health–low risk pond management methods	+++++	medium	adaptive	+	region s.i. and i. systems all farms	7.5 ± 1.9 (8)
8	Effect of pond conditions on predisposition to disease	+++	medium	strategic and adaptive	++	region s.i. and i. systems all farms	6.8 ± 1.8 (7)

Appendix 1. (cont'd) Descriptive statistics for research issues in the area of disease and health.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
9	Farm-level risk analysis and disease reduction	++++	medium	strategic and adaptive	+++	region s.i. and i. systems all farms	6.5 ± 1.7 (7)
10	Identification and description of base units for disease control (pond, farm, zone etc.)	++++	medium	adaptive and tactical	+	region all systems all farms	6.1 ± 2.0 (6)
11	Identification and risk assessment of routes of infection for major diseases	++++	short	strategic	++	region s.i. and i. systems all farms	6.2 ± 2.0 (6)
12	Improvement of sampling designs for health management activities	+++	short	strategic and adaptive	+	region s.i. and i. systems big farms	5.3 ± 2.2 (6)
13	Investigation of incidence of major viral diseases in wild stocks	+	short	strategic and adaptive	+	region all systems farms and fishing	4.0 ± 2.3 (3)
14	Studies of modes of transmission of viruses between shrimp	++++	medium	strategic	++	region all systems farms and fishing	6.3 ± 2.3 (6)
15	Clarification of basic defence mechanisms of shrimp against disease	+++	medium to long	strategic and adaptive	+++	region all systems all farms	6.8 ± 2.4 (7)
16	Development of practical methods of immunoprophylaxis for shrimp	+++++	long	strategic	+++	region all systems all farms	7.2 ± 2.5 (8)

Appendix 1. (cont'd) Descriptive statistics for research issues in the area of disease and health.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
17	Development of methods to measure stress in individual shrimp and shrimp populations	++++	medium to long	strategic	+	region s.i. and i. systems all farms	5.8 ± 2.4 (7)
18	Testing of efficacy of immunostimulants and vaccination	+++++	medium to long	strategic	++++	region s.i. and i. systems all farms	6.4 ± 2.4 (6)
19	Development of procedures for health certification of shrimp for export	+++	short	tactical	+	region s.i. and i. systems all farms	5.3 ± 2.2 (5)
20	Development of standard diagnostics	++++	medium	adaptive and strategic	++	region s.i. and i. systems big farms	6.5 ± 1.5 (6)
21	Improved real-time, pond-side disease diagnostics	+++++	medium	strategic and adaptive	+++	region s.i. and i. systems big farms	6.2 ± 1.7 (6)
22	Quality assurance and cross-calibration of disease diagnostic procedures in different laboratories— local, national, regional	+	short	adaptive and strategic	+	region s.i. and i. systems big farms	4.7 ± 2.1 (5)

Appendix 1. (cont'd) Descriptive statistics for research issues in the area of disease and health.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
23	Rapid diagnosis for virulence	+++	medium	strategic and tactical	+++	region s.i. and i. systems big farms	5.8 ± 1.9 (5)
24	Development of accreditation schemes for chemical agents	+++	short	tactical	+++	region s.i. and i. systems big farms	4.7 ± 1.8 (5)
25	Screening of new and natural sources of therapeutants (herbs etc.)	+++	medium	tactical and adaptive	++	region s.i. and i. systems all farms	5.1 ± 2.3 (5)
26	Studies on safe techniques (with respect to user, shrimp, environment) for eliminating carriers/reservoirs	++++	medium	tactical and strategic	++	region s.i. and i. systems all farms	5.5 ± 2.4 (6)
27	Development of safe methods for control of shrimp fouling	++++	medium	strategic	+++	region s.i. and i. systems all farms	4.8 ± 2.6 (5)
28	Residues of pesticides/heavy metals–disease interactions	+++	short	strategic and adaptive	+++	some countries all systems farms and fishing	4.9 ± 2.3 (5)

Appendix 1. (cont'd) Descriptive statistics for research issues in the area of disease and health.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
29	Studies on sub-lethal/chronic effects of toxicants on various shrimp life stages (toxicology)	++++	medium	strategic and adaptive	+	region all systems farms and fishing	5.3 ± 1.7 (5)
30	Interactions between nutrition and shrimp health	+++++	medium	strategic	+++	region s.i. and i. systems all farms	7.5 ± 2.0 (8)
31	Studies on biological control of disease in hatchery and farm (including vertical transmission of disease in broodstock)	+++++	medium	strategic and adaptive	++	region all systems all farms	7.3 ± 2.4 (7)

From high to low on a scale from +++++ to +.
[b]Short (1–2 yr), medium (2–5 yr), or long (5–10 yr) term.
[c]Strategic = long-term benefits; adaptive = adapt existing technologies; tactical = 'fire fighting'.
[d]From large, moderate, some or very little effort on a scale from +++++ to +.
[e]Country of application (ranging from regional to country); type of system, ranging from extensive (e.), semi-intensive (s.i.) to intensive (i.); group which benefits (ranging from small farms, big farms, community to fishing industry).
[f]From low to high on a scale from 1 to 10, respectively (s.d. = standard deviation).

Appendix 2. Descriptive statistics for research issues in the area of environmental impact assessment and monitoring.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
32	Assessment of causes of water quality deterioration	+++++	medium	strategic and tactical	++	region s.i. and i. systems all people	7.8 ± 2.2 (8)
33	Waste utilisation/management of waste from shrimp processing plants	+++	medium to long	strategic and tactical	++	region s.i. and i. systems processors	5.0 ± 2.6 (4)
34	Effluent management and waste treatment technologies	++++	medium	strategic and tactical	+	region s.i. and i. systems farms, fishing and community	7.5 ± 2.2 (8)
35	Reduction of pollutant loads through development of low pollution feeds	++++	medium	strategic and tactical	+	region s.i. and i. systems farms, fishing and community	6.9 ± 1.9 (7)
36	Management of pond sediments/sludge disposal	+++	medium	strategic, tactical and adaptive	+	region s.i. and i. systems farms, fishing and community	6.0 ± 2.4 (6)
37	Development of water quality standards and tests	++	short	adaptive	+++	region s.i. and i. systems big farms	4.6 ± 2.2 (4)

Appendix 2. (cont'd) Descriptive statistics for research issues in the area of environmental impact assessment and

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
38	Pollution of intake water and red tide monitoring	+++	short to medium	adaptive and tactical	++	region s.i. and i. systems big farms	4.4 ± 1.7 (5)
39	Costing of externalities	++	short	adaptive	++	some countries s.i. and i. systems all farms	2.9 ± 2.0 (2)
40	Assessment of real environmental impacts of shrimp farming	++++	medium to long	adaptive and strategic	++	region s.i. and i. systems farms, fishing and community	6.6 ± 2.1 (7)
41	Full cost–benefit of sustainability of shrimp farming	++	long	adaptive	+	region s.i. and i. systems farms, fishing and community	4.0 ± 2.2 (4)
42	Impacts on biodiversity	+	long	adaptive	+	region all systems farms, fishing and community	3.7 ± 2.2 (3)
43	Quantification of the fate of nutrients, antibiotics and other pond wastes in the environment	++	medium	adaptive	+	region s.i. and i. systems farms, fishing and community	4.7 ± 1.9 (5)

Appendix 2. (cont'd) Descriptive statistics for research issues in the area of environmental impact assessment and

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
44	Social cost–benefit analysis	+	medium	adaptive and strategic	+	region s.i. and i. systems farms, fishing and community	3.8 ± 2.6 (3)
45	Impacts on wild gene pools	+++	medium to long	adaptive and strategic	+	region all systems farms, fishing and community	3.3 ± 1.8 (3)
46	Assessment of optimal wet-land–farm ratios	++++	medium	adaptive and strategic	+	region s.i. and i. systems farms, fishing and community	4.0 ± 2.0 (4)
47	Strategies for community based, co-management, cooperation and contract farming in coastal zone management of shrimp culture	+++++	medium to long	adaptive and strategic	+	region s.i. and i. systems farms and community	6.0 ± 2.6 (6)
48	Development of plans and strategies for integrated coastal management	+++	long	adaptive and strategic	+	region s.i. and i. systems farms, fishing and community	6.4 ± 2.3 (6)
49	Identification, mapping and amelioration of acid-sulphate soils	+++	medium	adaptive and strategic	+	region s.i. and i. systems farms, fishing and community	4.2 ± 2.5 (3)

Appendix 2. (cont'd) Descriptive statistics for research issues in the area of environmental impact assessment and

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
50	Improved coastal land-use planning using geographical information systems and reflecting biophysical, social and economic characteristics	++++	medium to long	adaptive and strategic	+	region s.i. and i. systems farms, fishing and community	5.3 ± 2.4 (5)
51	Habitat monitoring	++	long	adaptive and strategic	++	region s.i. and i. systems farms, fishing and community	3.7 ± 1.9 (3)
52	Quantification of assimilative capacity of coastal waters	+++	long	adaptive and strategic	+	region s.i. and i. systems farms, fishing and community	6.0 ± 2.0 (6)
53	Integrated participatory approach to improve shrimp wastewater management	+++++	medium to long	adaptive and strategic	+	region s.i. and i. systems farms, fishing and community	6.8 ± 2.8 (7)

From high to low on a scale from +++++ to +.
[b]Short (1–2 yr), medium (2–5 yr), or long (5–10 yr) term.
[c]Strategic = long-term benefits; adaptive = adapt existing technologies; tactical = 'fire fighting'.
[d]From large, moderate, some or very little effort on a scale from +++++ to +.
[e]Country of application (ranging from regional to country); type of system, ranging from extensive (e.), semi-intensive (s.i.) to intensive (i.); group which benefits (ranging from small farms, big farms, community to fishing industry).
[f]From low to high on a scale from 1 to 10, respectively (s.d. = standard deviation).

Appendix 3. Descriptive statistics for research issues in the area of feed and nutrition.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
54	Feed management strategies	+++++	short to medium	strategic and adaptive	++++	region s.i. and i. systems all farms	6.7 ± 2.8 (7)
55	Reduction of feed conversion ratio (improve nutritional value)	++++	medium	adaptive	+++	region s.i. and i. systems farms and fishing	7.0 ± 2.4 (7)
56	Feed supplements	++	short to medium	strategic and adaptive	+++	region s.i. and i. systems all farms	5.7 ± 2.0 (5)
57	Assessment of the need to remove shrimp by-products from feed	+	short	adaptive and strategic	+	region s.i. and i. systems farms and fishing	4.3 ± 2.3 (5)
58	Screening of feed ingredients for pathogens and contamination	+++	short	adaptive	+	region s.i. and i. systems all farms	5.1 ± 2.7 (5)
59	Use of local raw materials versus imported feeds	+	short	adaptive	++	some countries s.i. and i. systems all farms	3.4 ± 2.5 (3)
60	Development of dietary stimulants	+++++	short to medium	strategic and adaptive	+	region s.i. and i. systems all farms	4.6 ± 2.1 (4)
61	Nutritional requirements unknown/unclear (digestibility)	+++++	medium	strategic	+	region s.i. and i. systems all farms	5.7 ± 2.3 (5)

Appendix 3. (cont'd) Descriptive statistics for research issues in the area of feed and nutrition.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
62	Impacts of medicated feeds	++++	medium	strategic and adaptive	++	region s.i. and i. systems all farms	4.9 ± 2.5 (4)
63	Improve protein digestibility and reduce utilisation of animal/marine protein	+++++	medium	strategic	++	region s.i. and i. systems farms, fishing and community	6.7 ± 2.8 (7)
64	Strategies to reduce impact of feed on environment	+++	medium	adaptive and strategic	+	region s.i. and i. systems farms, fishing and community	6.4 ± 2.7 (7)
65	Development of live feeds	+++++	medium	strategic and adaptive	++	region s.i. and i. systems all farms	5.0 ± 2.9 (4)
66	Development of farm-made feeds	++	medium	adaptive	++	region s.i. and i. systems small farms	3.7 ± 2.5 (3)

[a]From high to low on a scale from +++++ to +.
[b]Short (1–2 yr), medium (2–5 yr), or long (5–10 yr) term.
[c]Strategic = long-term benefits; adaptive = adapt existing technologies; tactical = 'fire fighting'.
[d]From large, moderate, some or very little effort on a scale from +++++ to +.
[e]Country of application (ranging from regional to country); type of system, ranging from extensive (e.), semi-intensive (s.i.) to intensive (i.); group which benefits (ranging from small farms, big farms, community to fishing industry).
[f]From low to high on a scale from 1 to 10, respectively (s.d. = standard deviation).

Appendix 4. Descriptive statistics for research issues in the area of genetics and broodstock.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
67	Endocrinology of broodstock maturation	+++++	medium to long	strategic and adaptive	++	region all systems farms and fishing	7.3 ± 2.8 (8)
68	Cost–benefit analysis of domesticated broodstock	+++	short	tactical	+	region all systems all farms	5.3 ± 2.7 (5)
69	Development of techniques for sustainable broodstock supply, preferably with domestic broodstock	+++	medium to long	strategic	++	region all systems farms and fishing	7.6 ± 2.1 (8)
70	Effect of environment and nutrition on broodstock quality	+++++	long	strategic and adaptive	+	region all systems farms and fishing	7.0 ± 2.0 (7)
71	Increase in fecundity and nauplius production from pond-reared broodstock to cost-effective levels	+++++	long	strategic	+	region all systems farms and fishing	7.3 ± 2.2 (7)
72	Studies on pond production performance of closed cycle produced postlarvae	++++	long	strategic	+	region all systems all farms	5.7 ± 2.0 (6)
73	Genetic improvement of shrimp	+++++	long	strategic	+	region all systems all farms	7.0 ± 2.8 (7)
74	Identification of base populations for selection	+++++	medium to long	strategic and adaptive	+	region all systems farms and fishing	5.7 ± 2.5 (6)

Appendix 4. (cont'd) Descriptive statistics for research issues in the area of genetics and broodstock.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
75	Survey on desirable characteristics for genetic enhancement and evaluation of hereditability of such characteristics	+++++	long	strategic	+	region all systems all farms	5.7 ± 2.5 (6)
76	Development of uniform criteria for assessing quality of fry	+++++	short	tactical	++	region all systems all farms	6.6 ± 2.3 (7)
77	Development of high health hatchery production methods	+++++	short	tactical and strategic	++	region all systems all farms	7.8 ± 1.7 (8)
78	Identification of natural stocks free of specific diseases	+++++	short to medium	tactical and strategic	+	region all systems all farms	6.0 ± 2.5 (7)
79	Identification and maintenance of healthy stocks for disease research	+++	short	tactical	++	region all systems farms and research	5.0 ± 2.4 (5)
80	Use of specific pathogen-free (SPF) broodstock for shrimp larval rearing	+++++	short to medium	tactical and adaptive	+++	region all systems all farms	5.2 ± 2.4 (5)

[a]From high to low on a scale from +++++ to +.
[b]Short (1–2 yr), medium (2–5 yr), or long (5–10 yr) term.
[c]Strategic = long-term benefits; adaptive = adapt existing technologies; tactical = 'fire fighting'.
[d]From large, moderate, some or very little effort on a scale from +++++ to +.
[e]Country of application (ranging from regional to country); type of system, ranging from extensive (e.), semi-intensive (s.i.) to intensive (i.); group which benefits (ranging from small farms, big farms, community to fishing industry).
[f]From low to high on a scale from 1 to 10, respectively (s.d. = standard deviation).

Appendix 5. Descriptive statistics for research issues in the area of farm and pond management.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
81	Study of pond dynamics and pond ecology	+++++	medium	adaptive	+++	region all systems all farms	7.6 ± 2.4 (8)
82	Better control of pond environment through biological agents and microbial ecology	++++	medium	tactical	+++	region all systems all farms	7.1 ± 2.2 (8)
83	Cost–benefit of best management practice i.e. systems development	++++	long	strategic	+	region s.i and i. systems all farms	5.6 ± 2.8 (5)
84	Assessment of carrying capacity of various culture systems (including effluent loading)	+++	medium	tactical and strategic	++	region s.i. and i. systems all farms	7.2 ± 2.4 (7)
85	Different crop management strategies (rotation, fallowing etc.)	+++	short to medium	tactical and adaptive	+	region s.i. and i. systems all farms	5.6 ± 2.1 (5)
86	Improve and increase application of relevant existing technologies from other disciplines (water treatment/pond dynamics/soil management etc.)	+++++	short to medium	tactical and adaptive	+	region s.i. and i. systems all farms	7.5 ± 1.8 (7)
87	Improvements in ambient seawater culture methodologies and pond management	+++++	medium	tactical and strategic	+	region s.i. and i. systems all farms	6.6 ± 2.5 (7)

Appendix 5. (cont'd) Descriptive statistics for research issues in the area of farm and pond management.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
88	Definition and promotion of country/system specific systems for shrimp aquaculture	+++	medium	tactical	+	region all systems small farms	4.6 ± 2.5 (4)
89	Determination of optimum management strategies for different pond systems (with regard to sophistication) and simple guidelines for application	+++++	medium	adaptive	+++	region all systems big and small farms	6.4 ± 2.9 (7)
90	Development of cost-effective, closed water management and treatment systems	++++	medium	adaptive	+++	region s.i and i. systems small farms	7.5 ± 1.9 (7)
91	Identification and control of factors important in development of different plankton blooms	+++++	medium to long	strategic	++	region s.i. and i. systems all farms	7.5 ± 1.9 (7)
92	Identification of simple, easily measured indicators of pollution in pond environments	+++++	short	tactical and adaptive	+++	region s.i. and i. systems all farms	6.5 ± 2.7 (7)
93	Studies on effects of chemical treatments/toxicants on pond biota	+++	short to medium	tactical and adaptive	++	region s.i. and i. systems all farms	6.2 ± 2.7 (7)

Appendix 5. (cont'd) Descriptive statistics for research issues in the area of farm and pond management.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
94	Development of polyculture	+++	medium	adaptive	+++	some countries e. and s.i. systems small farms	4.7 ± 2.6 (4)
95	Integration of alternative species into culture systems	++++	medium	adaptive	+++	some countries all systems all farms	5.3 ± 2.1 (5)

[a]From high to low on a scale from +++++ to +.
[b]Short (1–2 yr), medium (2–5 yr), or long (5–10 yr) term.
[c]Strategic = long-term benefits; adaptive = adapt existing technologies; tactical = 'fire fighting'.
[d]From large, moderate, some or very little effort on a scale from +++++ to +.
[e]Country of application (ranging from regional to country); type of system, ranging from extensive (e.), semi-intensive (s.i.) to intensive (i.); group which benefits (ranging from small farms, big farms, community to fishing industry).
[f]From low to high on a scale from 1 to 10, respectively (s.d. = standard deviation).

Appendix 6. Descriptive statistics for research issues in the area of remediation of farms and habitats.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
96	Assessment of alternative uses for pond soil	+++	short	adaptive	+	region s.i. and i. systems all farms and community	4.2 ± 2.4 (4)
97	Assessment of pond bottom soil remediation measures (in-pond)	+++++	short	adaptive	++	region s.i. and i. systems all farms	5.5 ± 2.8 (5)
98	Assessment of the necessity of sludge removal—real or not	++++	short	adaptive	+	region s.i. and i. systems all farms	4.9 ± 2.5 (5)
99	Rehabilitation case studies for abandoned shrimp ponds	+++++	medium	strategic	+	region all systems all farms and community	6.1 ± 2.7 (7)
100	Review of water/soil quality methods employed in examining acid sulphate soil or shrimp pond environments	++++	medium	strategic	+++	region all systems all farms	5.0 ± 2.2 (5)
101	Assessment of the range of techniques for pond rehabilitation	++++	short	adaptive	++	region s.i. and i. systems all farms	6.2 ± 2.2 (6)
102	Mangrove rehabilitation	+++	long	adaptive	+	region all systems farms, fishing and community	6.3 ± 2.7 (6)

[a]From high to low on a scale from +++++ to +. [b]Short (1–2 yr), medium (2–5 yr), or long (5–10 yr) term.
[c]Strategic = long-term benefits; adaptive = adapt existing technologies; tactical = 'fire fighting'. [d]From large, moderate, some or very little effort on a scale from +++++ to +.
[e]Country of application (ranging from regional to country); type of system, ranging from extensive (e.), semi-intensive (s.i.) to intensive (i.); group which benefits (ranging from small farms, big farms, community to fishing industry). [f]From low to high on a scale from 1 to 10, respectively (s.d. = standard deviation).

Appendix 7. Descriptive statistics for research issues in the area of socioeconomics, trade and licenses.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
103	Social and economic value of alternative 'land' use options	++	medium to long	adaptive and strategic	+	region all systems all farms and community	4.6 ± 3.3 (3)
104	Factors affecting success and failure of: (a) industry sub-sectors; and (b) contract farming, cooperatives, co-management and community-based management structures and institutions	++++	short to medium	tactical and adaptive	+	region all systems all farms and community	5.3 ± 2.8 (4)
105	Factors that determine profitability of farms and (a) economics of disease control and risk assessment; and (b) economics of closed versus open water management	++++	short to medium	tactical and strategic	+	region all systems all farms and community	6.2 ± 2.8 (5)
106	Post-General Agreement on Tariffs and Trade (GATT) developments, tariff and non-tariff barriers and their effects on farm profitability and the shrimp industry	+++	short	tactical	+	region all systems all farms and community	5.1 ± 2.4 (5)

Appendix 7. (cont'd) Descriptive statistics for research issues in the area of socioeconomics, trade and licenses.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
107	Information transfer regarding post-GATT trade-related restrictions	+++	short	tactical	+	region all systems all farms and community	4.6 ± 2.6 (4)
108	Review of government rules and regulations, and identification of coordinated strategies	++++	short to medium	tactical and adaptive	++	region all systems all farms and community	5.3 ± 2.3 (5)
109	Assessment of the effects of alternative policy options	++	short	tactical	++	region all systems all farms and community	3.6 ± 2.5 (3)
110	Land tenure and property right issues, and their relationship to social and economic issues	++	medium	strategic and adaptive	++	region all systems all farms and community	4.0 ± 2.6 (3)
111	Bio-economic assessment of integrated mangrove–shrimp farming and optimal mangrove–shrimp pond area ratios	++	medium	tactical and adaptive	+	some countries e. system all farms and community	5.5 ± 2.9 (5)

Appendix 7. (cont'd) Descriptive statistics for research issues in the area of socioeconomics, trade and licenses.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
112	Land use planning, licensing, tax as defensive or corrective measures	++	medium to long	adaptive	++	region all systems all farms and community	5.3 ± 3.1 (4)

[a]From high to low on a scale from +++++ to +.
[b]Short (1–2 yr), medium (2–5 yr), or long (5–10 yr) term.
[c]Strategic = long-term benefits; adaptive = adapt existing technologies; tactical = 'fire fighting'.
[d]From large, moderate, some or very little effort on a scale from +++++ to +.
[e]Country of application (ranging from regional to country); type of system, ranging from extensive (e.), semi-intensive (s.i.) to intensive (i.); group which benefits (ranging from small farms, big farms, community to fishing industry).
[f]From low to high on a scale from 1 to 10, respectively (s.d. = standard deviation).

Appendix 8. Descriptive statistics for research issues in the area of information transfer and training.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
113	Development of mechanisms for improving linkages—local/institutional	++	short to medium	tactical and adaptive	+	region all systems all farms and community	5.3 ± 2.5 (5)
114	Development of consumer awareness and protection programs to counter bogus claims made by salesmen	++	short to medium	tactical and adaptive	+	region all systems all farms and community	4.3 ± 3.0 (3)
115	Establishment of guidelines at a community level for sites and carrying capacity	++++	medium to long	strategic	+	region all systems all farms and community	6.3 ± 2.3 (6)
116	Extension services and education for farmers	+++++	medium to long	strategic and adaptive	++	region all systems farms and community	7.7 ± 2.3 (7)
117	Find out how farmers obtain information	+++	short	tactical	++	region all systems all farms	5.6 ± 2.6 (5)
118	Importance of social structure in extension activities and development of culturally appropriate approaches	++	medium	strategic	++	region all systems all farms and community	4.7 ± 3.0 (4)

Appendix 8. (cont'd) Descriptive statistics for research issues in the area of information transfer and training.

No.	Research issue	Impact on productivity[a]	Achievability (time frame)[b]	Importance[c]	Ongoing research (past and present efforts)[d]	Application of research (i.e. target group)[e]	Priority mean score ± s.d. (median)[f]
119	Improvement of farmer awareness of downstream environmental impacts	++++	short to medium	tactical and adaptive	+++	region all systems all farms and community	7.0 ± 2.4 (7)
120	Development of cost-effective training and technology transfer methods to overcome inadequacies in the transfer of information from research to farm	++++	medium	adaptive	++	region all systems all farms and community	7.5 ± 2.2 (8)
121	Potential implications of extension service privatisation	+++	medium to long	adaptive	++	region all systems all farms	4.7 ± 1.8 (5)
122	Promotion of regional cooperation in information transfer and extension	+++	medium	adaptive	+++	region all systems all farms	6.4 ± 2.5 (7)

[a]From high to low on a scale from +++++ to +.
[b]Short (1–2 yr), medium (2–5 yr), or long (5–10 yr) term.
[c]Strategic = long-term benefits; adaptive = adapt existing technologies; tactical = 'fire fighting'.
[d]From large, moderate, some or very little effort on a scale from +++++ to +.
[e]Country of application (ranging from regional to country); type of system, ranging from extensive (e.), semi-intensive (s.i.) to intensive (i.); group which benefits (ranging from small farms, big farms, community to fishing industry).
[f]From low to high on a scale from 1 to 10, respectively (s.d. = standard deviation).

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