

**Biophysical Survey and State of Sustainability Assessment for Coastal Shrimp
Aquaculture: A Case Study of the Upper Gulf of Thailand.**

by

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ABSTRACT

Thailand is currently the world's leading producer of farmed shrimp. Shrimp farming in most coastal regions has experienced explosive growth primarily through the intensification of methods and the expansion of culture area. The industry generates a combined annual revenue of \$US 2 billion to produce some 229,000 MT of farmed shrimp. This dominance in the shrimp industry, representing approximately one-fifth of global total, has only been achieved by a substantial increase in shrimp farming effort. The potential for export revenue has also attracted high risk capital and has been nationally supported. The 'success' in the application of these intensive monoculture methods can be attributed to the use of adverse practices and at the expense of the biophysical environment.

The sustainability of the industry is now being seriously questioned. This questioning has fostered a realization of the inherent problems at all levels ranging from farm-level practices to national policies. The assumption that coastal shrimp aquaculture is a low-risk high-profit operation is no longer valid. Examples of the negative effects of the rapid development of coastal areas to establish shrimp farms are numerous and widespread. Severe environmental, human health and socioeconomic impacts are now prevalent in many shrimp farming regions. This research focused on the collapse of the Upper Gulf shrimp industry from 1989 to 1991. This region, formerly the highest shrimp producer, now experiences a recurring pattern of shrimp farm failure. Large scale abandonment of shrimp farms located on previously productive areas for other land uses has led to land alienation. The extent of degradation and environmental damage is severe, potentially irreversible, and to date has not been restored or rehabilitated.

This interdisciplinary thesis conducted an in-depth analysis focused on the biophysical aspects of sustainability at both the farm- and pond-level of the Upper Gulf province of Samut Sakhon. Direct field observations and data collection, using qualitative and quantitative methods, demonstrated the complex nexus of environmental (physical, biological and chemical) and socio-economic factors which have contributed to the current status of the industry. The results indicate that fundamental changes are required to improve the sustainability of the industry. In sharp contrast to these results, the industry continues to expand rapidly in other regions of Thailand and to other countries seeking to cash in on the potential export earnings. This prevalent mentality suggested an immediate response and forced the author to organize the research using an integrative approach to assess the sustainability issues. Previous work on sustainability has been concentrated along disciplinary lines, and dominated by sectoral interests. Most studies have not considered the fundamental requirements of sustainability i.e. integration and equal consideration of socioeconomic, economic and environmental concerns.

Field observations from Samut Sakhon found the pattern of shrimp farm failure followed a characteristic cycle. Investigation of this cycle determined the many causes of farm cycle failure. Further, the observed responses to shrimp farm failures has resulted in a number of post production land uses. These responses were grouped into a 'report card' of progress towards sustainability.

A complete sustainability analysis of the industry was then the logical next step. Five key sustainability indicators, grouped in either: environmental, human health-ecosystem health or socioeconomic, were selected to reveal the negative trends observed in the field investigation. For the moment, they are almost all negative in terms of sustainability. Analysis of the negative trends revealed by the indicators led to the conclusion that

These barriers were organized in terms of institutional factors. Solutions to overcoming these barriers to sustainability are proposed by reverse application of these factors in a positive way. This thesis makes a substantial contribution to analyzing the sustainability of Thai shrimp farms. However, the research on sustainability is far from complete. The author suggests several future key indicators for further work that was not possible within the scope of this thesis.

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SELECTED THAI EQUIVALENTS

Ao	Bay, gulf
Amphoe, Amphur	District, secondary administrative center
Ban	Village, small community
Changwat	Provincial capital city, primary administrative centre
Khlong	Stream, canal (central only)
Mae	River
Mae Nam	Large river
Muang	Town, city
Mu Ban	Village
Tambol	Group of villages, tertiary
Wat	Temple

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1. INTRODUCTION

Societies, both ancient and modern, have long exploited natural resources by seeking to maximize immediate short term profit at the expense of the environment. Intensive shrimp farming, as it has developed in Asia to date, falls into this unfortunate tradition of resource exploitation. The current worldwide growth of the aquaculture industry has raised questions of sustainability that are related to both on-site and off-site resource requirements and impacts. It is no longer necessary to make the argument that long-term sustainable development of shrimp farming operations can only be attained through rational environmental management. A number of ecological disasters, emerging trends and visible results of short term and ill considered operations have illustrated the effects of neglecting environmental impacts. Through analysis of the social, economic and environmental factors affecting the industry the shrimp culture industry in Thailand, this thesis develops recommendations for reversing the negative trends and moving towards sustainability.

The culture or practice of raising aquatic food species has a long history. The present day industry is increasing at a rapid rate throughout the world (OECD, 1989). In 1993, aquaculture production accounted for 16 % of the world's total fishery production and 23 % of food fish supplies (Pullin, 1995). FAO (1990a) estimated that 56 % of the 14.47 million metric tonnes (MT) of aquaculture production in 1988 came from the brackish and marine environment. Over the past decade Asia has emerged as the leading supplier of farmed shrimp to the world market. This rapid growth can be attributed to a trend toward the intensification of shrimp farming methods. The above trend has been supported by the combination of fast growing economies, favorable climate, abundant low cost land which is ideally suited to aquaculture, low labor costs and enterprise. The combination of these factors has resulted in Asia's prodigious output which now makes up about 85 % of the world's farmed shrimp¹. This trend is driven by market forces and increased competition for wild coastal fishery resources (GESAMP, 1991). Rapid return on investment has attracted high risk capital. While

¹ The small number of developing countries in Asia that produce this significant percentage of the total output are China, India, Indonesia, the Philippines, Thailand and Vietnam.

this situation creates increased job opportunities and higher income for some, it also has had an impact on each country's natural resources and environment.

Despite the fact that intensive operations have only expanded in the last decade to a global scale, there are already serious concerns regarding the 'sustainability' of these operations. Different environmental (physical, chemical and biological) and socio-economic problems call into question the sustainability of current production and future viability of the industry. The most severe examples involve the failure and subsequent widespread abandonment of areas used for culture in the various shrimp farming regions. For example, there is presently 3,555 ha of abandoned culture area in Thailand's Samut Sakhon province alone (OEPP, 1994b)². The harmful effects of shrimp farming have also created widespread problems for coastal dwellers as well as coastal ecosystems.

Thus, shrimp aquaculture once hailed as a promising export earner, is now causing social and environmental havoc in Asia and many Third World countries. Farming and fishing communities throughout the region are only now recognizing the intrusion into their lands and the destruction of land and water resources by aquaculture farms (Khor, 1995). Since the late 1970's, shrimp aquaculture has been a powerful catalyst of social and ecosystem change along the coast of many countries. As this thesis will demonstrate, if shrimp aquaculture is to be sustainable, issues of competing coastal activities must be resolved, and ecosystems qualities essential to the profitability of the industry need to be maintained.

1.1 Background and rationale

Thailand was chosen for this research as it is currently the largest producer of cultured shrimp in the world. Thailand has achieved this level of production by intensifying its existing shrimp culture industry through the transfer of Taiwanese technology. Ironically, the repeated collapse of the Taiwanese industry has demonstrated the failings of this culture system. Increasing signs of unsustainability in Thailand, that are linked to intensive culture, provide an ideal opportunity to study the underlying causes of

² 'Abandonment' is the action taken by farmers who cannot sustain culture. Their action once the shrimp farm fails is to vacate the site or leave it idle. Either way the land is not used for shrimp aquaculture.

declining productivity and farm failure. This is of crucial importance as other developing countries, most recently Mexico, are adopting these Taiwanese/Thai style culture techniques. The unsustainability of the cash-crop approach to shrimp farming suggests that research on new methods and approaches to shrimp production which can be integrated into the overall sustainable development of coastal resources would be valuable. This provided the rationale for the project.

From an ecological perspective, shrimp farming in Thailand is an example of monoculture which emphasizes a single species rather than an ecosystem. The single species (*Penaeus monodon*) is almost without exception the organism being referred to throughout the thesis when the word shrimp is used.

Thailand's province of Samut Sakhon was selected as the study area. The province experienced a widespread failure of its intensive coastal shrimp culture industry during the period between 1990 to 1991.

Samut Sakhon provided a complete example of the overall and emerging problems within the global shrimp culture industry. The close proximity of the province to Bangkok allowed for complete field sample collection and return in one day. Access to the shrimp farms of the region for field sampling was greatly assisted by the cooperation of the Thai Department of Fisheries (DOF), and the Coastal Aquaculture Development Center in the province of Samut Sakhon. Field staff from the center aided with sample collection and in the obtaining of permission from shrimp farm owners. In light of events within the industry, this area has become the focus of numerous research studies examining the issues of sustainability in intensive shrimp farming operations. Significant amounts of comparative and reference data have become available.

1.2 Scope of the research

Although the issues and the topic of intensive shrimp culture will be introduced from a global perspective, the detailed examination here, will focus on the shrimp farming trends that have emerged in the Upper Gulf of Thailand region with emphasis on the province of Samut Sakhon. The research that was undertaken had several components:

1. A detailed assessment of the current state of shrimp farming in the province of Samut Sakhon. The assessment necessarily includes the historical development of shrimp farming in the region as well as a review of intensive shrimp farming practices, regulation and impacts.

This assessment was supported by the preparation of several detailed technical reviews of shrimp farming by the author while at the Network of Aquaculture Centres in Asia-Pacific (NACA), and extensive discussions with shrimp farmers throughout Thailand and the Upper Gulf region. Farm-level contacts in the province of Samut Sakhon were initiated through direct involvement with several international research projects staged from the office of NACA located in Bangkok. The experience of living in Thailand for an extended field study program (8 months) and collaboration with fellow researchers in the region allowed for direct observation and access to documentation required for this level of assessment.

2. Field data on water quality, including pesticide and heavy metal contamination was collected at five sites in Samut Sakhon. The results were compared to legislated regulatory values and to historical data from informed Thai sources.

3. Responses, statistical and anecdotal, to productivity collapse and the subsequent methodological changes in culture practices, were documented to complete the information that was required for a **State of Sustainability** assessment.

1.3 Assessment of sustainability of the shrimp culture industry in Thailand

The primary goal of the research program was to conduct a biophysical and socioeconomic assessment that would contribute to the development of sustainable coastal shrimp aquaculture in the region. To achieve this goal, two principal objectives were established for the presentation of the results:

1. To conduct an analysis of the barriers and opportunities for solutions to the current environmental problems facing the industry using the information from the biophysical and socioeconomic assessment. By analyzing the state of sustainability,

to develop strategies to support existing shrimp farms and evaluate the potential for rehabilitation of abandoned areas.

2. To present the outcomes of the analysis as a concise set of recommendations that will assist in forming a general sustainability framework applicable to future shrimp farming developments in Thailand and elsewhere.

1.4 Supporting areas of investigation

The research program and analysis of the results are interdisciplinary in approach. It is important to recognize the extent of the supporting areas of investigation that have been required. To complete the biophysical and socioeconomic assessment, the following objectives were addressed:

1. To present a global, national and regional description and analysis of the coastal shrimp aquaculture industry.
2. To provide a review of the total production, culture methods, natural resource requirements, historical development, environmental impacts and emerging patterns in the industry.
3. To present an overview of the aquaculture and non-aquaculture anthropogenic inputs to the coastal zone. This includes examination of coastal water pollution sources as compared to existing historical data including the externalities affecting the industry.
4. To analyze existing government regulations and policies regarding coastal aquaculture, and to review the water quality and effluent standards that apply to coastal aquaculture.
5. To provide a detailed description of shrimp culture in Samut Sakhon based on experience in Thailand, current literature, surveys and through a technical field sampling program consisting of: physical and chemical water quality parameters,

pesticides and heavy metal levels and plankton enumeration information.³ Samples collected from the province of Samut Sakhon will be used for comparison to the above standards.

6. To identify the general and specific factors underlying the productivity declines observed throughout the industry. Further, to examine the responses to this productivity loss in the province of Samut Sakhon.
7. To identify the factors to be considered at different stages of shrimp farm development. These stages include both the pre-farming stage and during on-going farm operations.

1.5 Role of sustainability as an organizing concept in the study of shrimp culture

Sustainability assessment has been the concept around which the project has been developed. A survey of the definitions of sustainable development, or sustainability, and the application of these terms to shrimp aquaculture is presented to lay the groundwork for the approach. The organization of the thesis using sustainability and a reporting framework follows. In addition, for those unfamiliar with the sustainability literature, a number of key concepts and definitions are presented at the end of this chapter in Section 1.7.

1.5.1 Sustainable development, sustainability, sustainable and unsustainable shrimp aquaculture

There are many definitions in the literature of 'sustainable development' and 'sustainability'. Discussions and detailed studies of these concepts virtually exploded following the release of the Brundtland Report in 1987. A number of agencies have since released modified definitions of 'sustainable development' for their respective interests. Sustainable development, following from the WCED report, was defined by the Food and Agriculture Organization of the United Nations (FAO) in 1988 as:

³ Plankton (Phytoplankton and Zooplankton) - Passively floating or weakly motile organisms. Planktonic plants are referred to as phytoplankton, and planktonic animals are referred to as zooplankton.

“...the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant and genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable.”

Sustainable shrimp aquaculture will be considered as the ability to grow shrimp indefinitely (and profitably) such that the farm, all supporting ecosystems and socioeconomic structures are not adversely affected. A sustainable activity considers ecological, social and nutritional security to have equal importance. Conversely, unsustainable shrimp aquaculture is simply that which is unable to maintain long-term biological and economic viability and has an overall deleterious effect upon the coastal environment.

1.5.2 Assembling the components for the sustainability assessment

Several components are essential to the assessment and analysis of sustainability. In the thesis, the sustainability analysis utilizes methods and approaches developed in previous sustainability studies. The methods are the use of a sustainability report card, a sustainability framework to organize the information, and the selection of key indicators to identify trends. Upon completion of the biophysical survey, the components are utilized to conduct a state of sustainability assessment for coastal shrimp aquaculture. The Upper Gulf of Thailand case study region has been the focus of the assessment. Each of the components is described below.

1.5.3 Report cards

Report cards can be utilized to indicate progress towards achieving sustainability. Report cards seek to subjectively rate complex issues and do not contend to present definitive 'hard science' based information, although the information behind a particular issue may have been decided by such studies. The intent of the report card is to assemble a consensus opinion from a number of sources and to provide comparative information. An example would be the sustainable development report card for Canada as compared to the rest of the world on a number of topics (e.g. climate change,

biodiversity, forests etc.). Such a report card has been suggested by David Runnalls in 1995 (Table 1.1).

Table 1.1 Sustainable development report card, 1995 (Developed by David Runnalls, Senior fellow, International Institute for Sustainable Development)

Topic	World	Canada
Climate change	C-	D
Biodiversity	C	C
Forests	D	B
Marine conservation	D	D+
Ozone depletion	B-	A
Finance for developing countries	C	D
Trade and Environment	C+	C-

In the thesis, the sustainability report card presented in Chapter 5 Section 5.10 is based on observed responses to shrimp farm cycle failure in the Upper Gulf province of Samut Sakhon. The report card is just one component in the overall method of analyzing the sustainability of shrimp farming.

1.5.4 Developing an organizing framework and selecting key indicators

Hodge (1995) presents a systemic framework for assessing progress towards sustainability (Figure 1). In further work, Hodge develops indicators to support this framework. Figure 2 presents the sustainability framework employed in the Agenda 21 for human settlements. This figure was developed by the United Nations Conference on Environment and Development (UNCED) in 1992 and further emphasizes the connection between ecosystems and humans. In the development of such models, the complexity that results often defeats the original purpose. Data is not available to analyze each of the entries in the model. More seriously, integration of the multiplicity of the factors to arrive at solutions or recommendations is almost unachievable. For these reasons, a much simpler framework has been selected on a trial basis for the thesis. This simple framework is shown in Figure 3. The selection of key indicators reflects the equal importance of both humans and ecosystems in sustainability analysis. The indicators measure progress towards the objectives of human and ecosystem well-being and are interpreted in terms of the institutional factors. The fundamental role of values in determining the response of institutions, and even the selection of indicators is recognized at the base of the pyramid.

1.5.5 The schematic framework for analyzing progress towards sustainable intensive shrimp culture

The current case study of the environmental problems related to the Thai intensive shrimp aquaculture industry, has conditions that are acute and readily identified by direct observation such as: excessive and widespread mangrove removal, increased land salinization, large displacement of rural communities, destruction of traditional livelihoods, and pollution of receiving waters. These trends are symptoms of a number of barriers to achieving sustainability in the industry in Thailand that currently exist. To really understand the environmental problems related to intensive shrimp aquaculture systems, we need to examine factors that affect environmental change. Six institutional factors form the critical elements of the sustainability framework shown in Figure 3.⁴

There is a paradox in the identification of the critical factors as barriers (Table 1.2). In analyzing them in relation to sustainability it was soon realized that appropriate re-application of the same factors positively would lead to solutions to the negative trends. Accordingly, they are referred to as **"Barriers to be Overcome/Opportunities for Solutions"** and discussed first in terms of the negative trends. Subsequently the potential of the same factors for progress toward sustainability is analyzed.

Table 1.2 Institutional factors in a sustainability framework: barriers and opportunities.

-
1. The economic system
 2. Science and technological innovation
 3. Institutional structures
 4. Policies and legislation
 5. Planning and information systems
 6. Ecological monitoring systems

It is the purpose of the documentation in chapters 2 to 5 to establish a thorough basis for assessing these factors. Selecting indicators that can measure progress towards sustainability that may result from appropriate changes in the six areas is an equally important task.

⁴ The headings used in this thesis to categorize the 'barriers' are adopted from an analysis proposed CCME (1993) and were applied to the Thai intensive shrimp aquaculture industry.

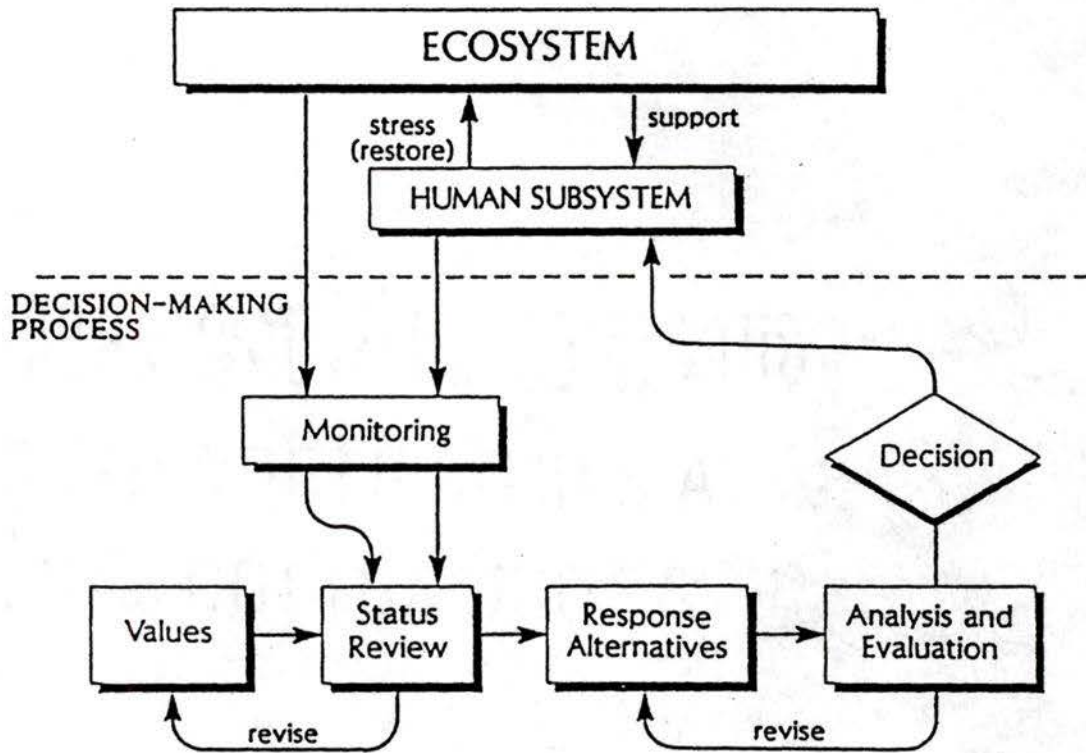


FIGURE 1. A SYSTEMIC FRAMEWORK FOR ASSESSING PROGRESS TOWARD SUSTAINABILITY (HODGE, 1995)

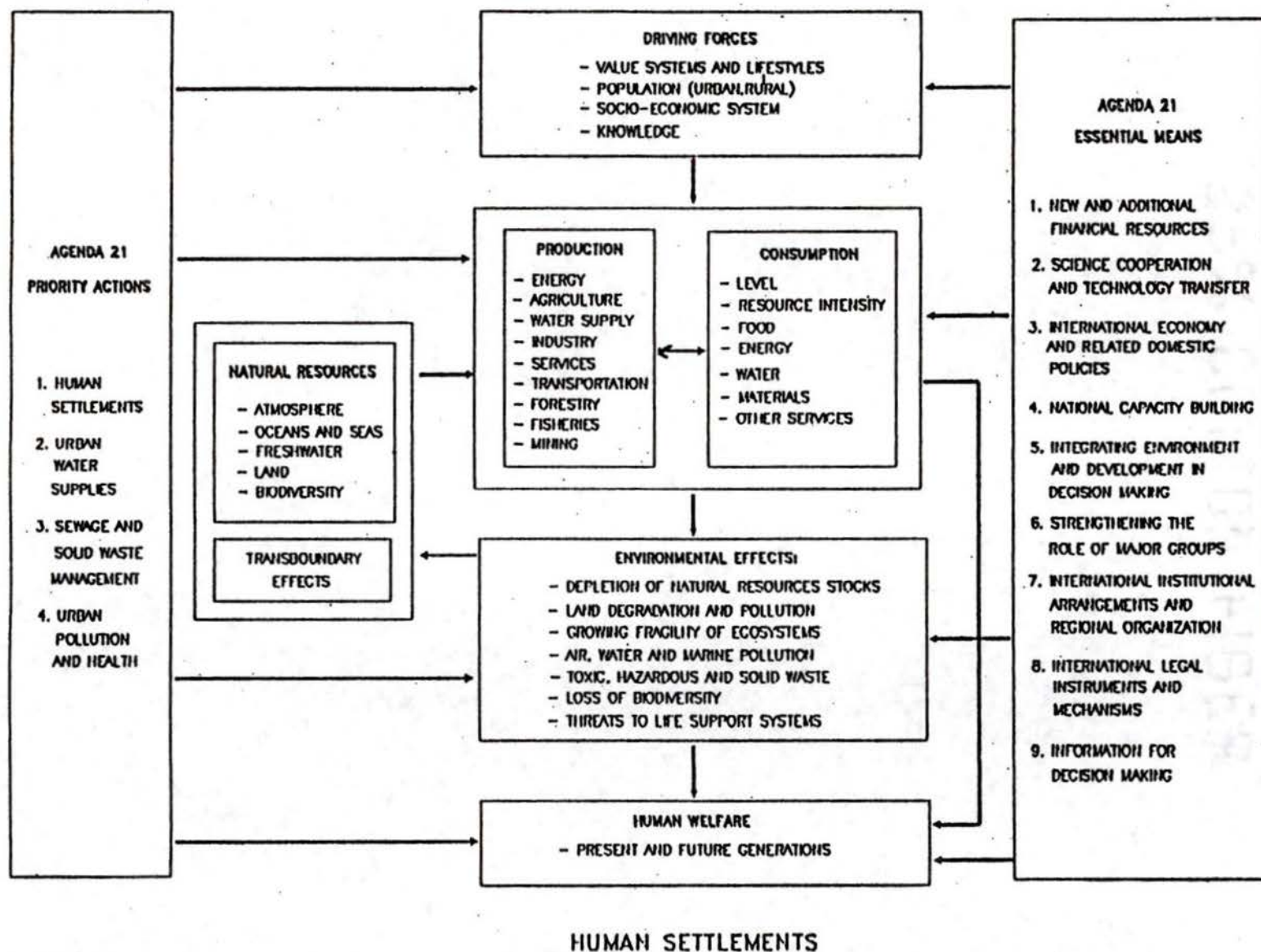


FIGURE 2: SUSTAINABILITY FRAMEWORK EMPLOYED IN THE AGENDA 21 (UNCED, 1992)

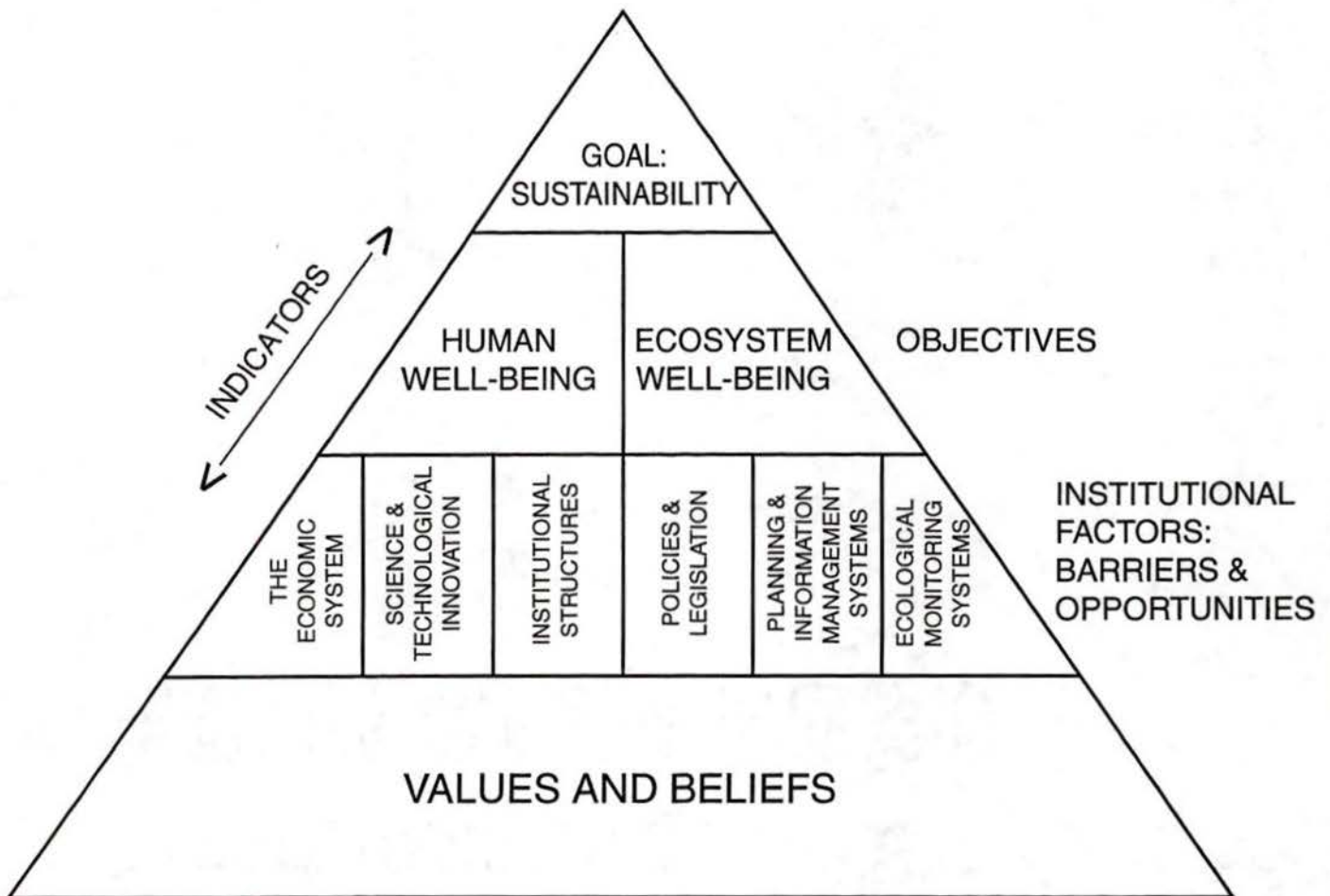


FIGURE 3. SCHEMATIC MODEL FOR SUSTAINABILITY

Note: See Hodge (1995) for a systemic framework for assessing progress towards sustainability (Figure 1); and UNCED (1992) for the sustainability framework employed in Agenda 21 (Figure 2)

1.6 Structure of the thesis

The structure of the thesis is developed on a pragmatic basis to carefully define the problem and document information to facilitate the difficult task of attempting a sustainability assessment. The structure of the thesis is as follows:

1. In Chapter's 2 and 3 a technical and socioeconomic evaluation of the shrimp culture industry for both Thailand and the case study region is presented. The two chapters address the biophysical requirements of varying degrees of intensity in culture, introduce the environmental impacts and review the economic and governance frameworks in the country.

Such a solid grounding is necessary to undertake the analysis of the six key factors in the framework (Figure 3).

2. Next, in Chapter 4, additional direct field research in the case study region is reported, focusing on water quality and environmental impacts.

3. All of the results are compiled in Chapter 5 to provide a sustainability scan of current conditions and responses. The analysis is summarized in a report card approach.

4. In Chapter 6, the task of selecting key indicators and analyzing the key factors for positive solutions is addressed.

5. Specific recommendations for sustainability in the Thai shrimp culture industry are presented in a final summary in Chapter 7.

1.7 Key concepts and definitions

Several coordinating principles advanced in the literature are useful to the sustainability analysis. Concepts proposed by Rees (1994) will be applied in the examination of the shrimp farming industry. These concepts include **appropriated carrying capacity (ACC)**, **ecological deficit** and **sustainability gap**.

ACC refers to the biophysical resource flows and waste assimilation capacity appropriated per unit time from global totals by a defined economy or population. In this study, ACC implies 'exploitation' through the 'appropriation' of resources. The intensification of shrimp farming concentrates effort using large areas of land and high volumes of water.

Use of these biophysical resources produces wastes beyond the capacity of the regional environment. In several places in the thesis the concept of carrying capacity has already been used. When the author refers to the capacity of an ecosystem to support healthy organisms while maintaining its productivity, adaptability, and capability of renewal, carrying capacity is inferred. The shrimp farming industry will eventually face two options with respect to carrying capacity. Reduce all industry operations to previous traditional methods or manage the industry within the modern industrialized economy so as not to damage ecological integrity. The latter represents the more practical option.

Ecological deficit is the level of resource consumption and waste discharge by a defined economy or population in excess of locally/regionally sustainable natural production and assimilative capacity (also, in spatial terms, the difference between that economy/population's ecological footprint and the geographic area it actually occupies). In this thesis, the ecological deficit is created by the level of resource consumption (land, water) which exceeds local/regional natural production of resources. In addition, the waste discharged from shrimp farms in most cases exceed the available assimilative capacity. In spatial terms, this then suggests that the combined resource consumption and waste production of intensive shrimp farms represents that which would normally be produced from much larger area using different methods of production. Comparison to semi-intensive operations provides example. This intensity of shrimp farm operates using much less water and feed inputs and generate much less waste in terms of effluent BOD and accumulated wet sediments. Deficit calculations for Colombian shrimp farms support this statement. Evidence from Thailand suggests a similar deficit exists.

The **sustainability gap** is a measure of the decrease in consumption (or the increase in material and economic efficiency) required to eliminate the **ecological deficit** (can be applied on a global or regional scale). In this thesis, field observations determined three factors that are directly contributing to the sustainability gap. The harvesting rate of renewable resources (e.g. mangroves) exceeds regeneration; extraction of non-renewable

resources exceeds rates which renewable resource substitutes are developed; rate of waste generation (BOD, accumulated sediments) exceed rates that can be assimilated by the environment. These concepts will provide the framework for discussion of area-equivalent sustainability indicators.

Several other concepts represent new and evolving approaches to looking at the environment and activities undertaken within the environment. These include the **precautionary principle**, **reverse onus** and the **precautionary approach**. The **precautionary principle** was stated in the 1992 Rio Declaration as follows:

“Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for post-postponing cost-effective measures to prevent environmental degradation.”⁵

The **precautionary principle** requires authorities at entrepreneurial, national, regional and international levels to take preventive action where there is risk of severe and irreversible damage to human beings by technology. Its characteristic attribute is that action is required even in the absence of certainty about the potential for damage and without having to wait for full proof of the cause-effect relationship. In addition, when there is disagreement on the need to take action, the burden of providing the proof is reversed and placed on those who contend that the activity has or will have no impact. This is referred to as the concept of **reverse onus**. Documents have now begun to refer to the precautionary approach which is subtly different. It has a softer requirement, recognizing that there are differences in “local capabilities” to apply the **precautionary principle** and emphasizing the need for the “cost effectiveness” of action (i.e. taking into account economic and social costs).

The term **ecosystem** can be more formally defined for purposes of the sustainability analysis. An ecosystem consists of plants, animals and other organisms together with the physical (non-living) components of their environment. A **degraded ecosystem** refers to an ecosystem where diversity and productivity have been so reduced that they are unlikely to recover without rehabilitation or restoration measures (IUCN/UNEP/WWF, 1991).

⁵ Principle 15, Rio Declaration, August 12, 1992 U.N. Conference on Environment and Development.

A call for increased recognition of ecological processes has prompted the development of methods to better understand human interactions within the ecosystem. Approaches are evolving and include what has come to be referred to as **ecosystem-based management (EBM)**.⁶ EBM has now been used in several applications including the management of parks and protected areas in Canada. The application of such management approaches are required in the shrimp farming industry. The use would be in assessing all aquaculture developments in terms of the relationship and potential effects of the proposed activity to the ecosystem. Maintaining ecosystem integrity would be a primary goal.

An important consideration in sustainability assessments put forward by IJC (1995) and others is the connection between **human versus ecosystem well-being**. Ecosystem health internalizes human well-being as part of the environment, while a human health focus would internalize the environment for individual and community well-being. This important aspect of any sustainability assessment basically states that whatever we do to the ecosystem ultimately we do to ourselves! Hodge's systemic framework for assessing progress towards sustainability illustrates this connection (Figure 1).

Recommendations from the sustainability analysis will include some measures to restore and rehabilitate damaged ecosystems. Definitions for these terms are appropriate. **Rehabilitation**, as defined by IUCN/UNEP/WWF (1991), is to return a degraded ecosystem or population to an undegraded condition, which may be different from its original condition and **restoration** is to return a degraded ecosystem or population to its original condition. Johnson and Moore (1995) define **mitigation** as the situation where opportunities for the direct restoration or rehabilitation of an impaired biological resource are technically limited, excessively costly, or likely, to be ineffectual, but opportunities for significant benefits to the impaired resource or similar resources exist elsewhere nearby. The concept of "**no net loss**" is included in mitigation. In this approach, alternative habitat is created artificially. Its validity is strongly contested by ecologists.

The proposed solutions will also call for the increasing application of **ecological risk assessment (ERA)** techniques. **ERA** is considered both a tool and a new and evolving

⁶ This approach is said to have originated in response to the call for the integration of biological, physical and socioeconomic information in the way we examine ecosystems. However, most view its development as a reasoned response to widespread environmental deterioration (Woodley and Forbes, 1995).

technique for assessing progress towards sustainability. **ERA** as defined by IJC (1995) is a process that evaluates the probability that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. The science of risk assessment addresses and quantifies, hazard identification, dose-response (or exposure-response) relationships and exposure determination, which lead to risk characterization. Risk characterization is the primary scientific input into risk management.

2. SHRIMP CULTURE IN THAILAND: A CURRENT TECHNICAL AND SOCIOECONOMIC EVALUATION (NATIONALLY AND FOR SAMUT SAKHON CASE STUDY REGION)

2.1 Introduction

This section reviews available technical and socioeconomic information, both nationally and for the Samut Sakhon case study region, on shrimp culture with the aim of answering the following questions: What are the biophysical resource requirements of shrimp aquaculture in Thailand? What are the aquaculture management systems and methods? What levels of production are achieved globally, for Southeast Asia, Thailand, and Samut Sakhon and what are the environmental impacts resulting from this production? What are the salient historical events behind the development of shrimp farming and what legislative and relevant government are controls in place? Lastly, what are the inputs to the coastal zone from all activities, including aquaculture, and how can we categorize them for future discussion. The aim at the end of this section is for the reader to be informed of the relevant issues emerging from the activity of shrimp farming. Armed with this information the detailed assessment will follow.

2.1.1 Location of the study region

The research was conducted in Thailand which is located in Southeast Asia in the center of the Indo-Chinese peninsula between latitude 6° to 21° North and longitude 98° to 106° East (Figure 4). Most of the total country area of about 51,311,500 ha is located in the tropical zone of Southeast Asia in the southeastern corner of Asia. Thailand is bounded on the north by Myanmar and the Lao People's Democratic Republic, on the east by the Lao People's Democratic Republic and Cambodia, on the south by the Gulf of Thailand and Malaysia and on the west by Myanmar and the Andaman Sea. The length of Thailand from north to south is about 1,648 km and the widest part from east to west is about 780 km.

The field study involved working in the physiographical region of the central plain, known as the 'Upper Gulf' region, and contains the provinces of Chonburi,

Chachoengsao, Samut Prakan, Bangkok, Samut Songkhram and Samut Sakhon (Figure 5). The Upper Gulf province of Samut Sakhon was the location of the detailed field study. Samut Sakhon is located in the northernmost area of the Gulf of Thailand between 13°25' to 13°45' latitude North and 100°00' to 100°25' longitude East and covers an area of 851 km² (Figure 6). It is located two hours drive southwest of Bangkok and borders on the provinces of Ratchaburi and Nakhon Pathom in the north, the Gulf of Thailand to the south and Samut Songkhram and Ratchaburi provinces to the west.

2.1.2 Provincial administration and population of Samut Sakhon

The province of Samut Sakhon is divided into three districts (Amphoe Muang, Ban Phaeo, and Krathum Baen), 36 sub-districts (or Tambol) and 280 villages (Mu Ban) for administrative purposes. In 1992, the population was approximately 455,563 people with a population density of 5.35 persons/ha. The urban to rural inhabitant percentage was 39 to 61. Table 2.1 presents the changes in the population density of the province of Samut Sakhon from 1978 to 1987.

Table 2.1 Changes in the population density of the province of Samut Sakhon from 1978 to 1987 (Data from the Office for Central Civil-Registration, Department of Local Administration Ministry of Interior and cited in OEPP, 1994b)

Year	Population	Density (persons/ha)
1978	254,514	2.99
1979	259,022	3.04
1980	265,464	3.12
1981	270,744	3.18
1982	278,949	3.28
1983	296,714	3.49
1984	301,631	3.54
1985	315,373	3.70
1986	327,677	3.85
1987	334,170	3.93

Note: Provincial land area of 85,100 ha

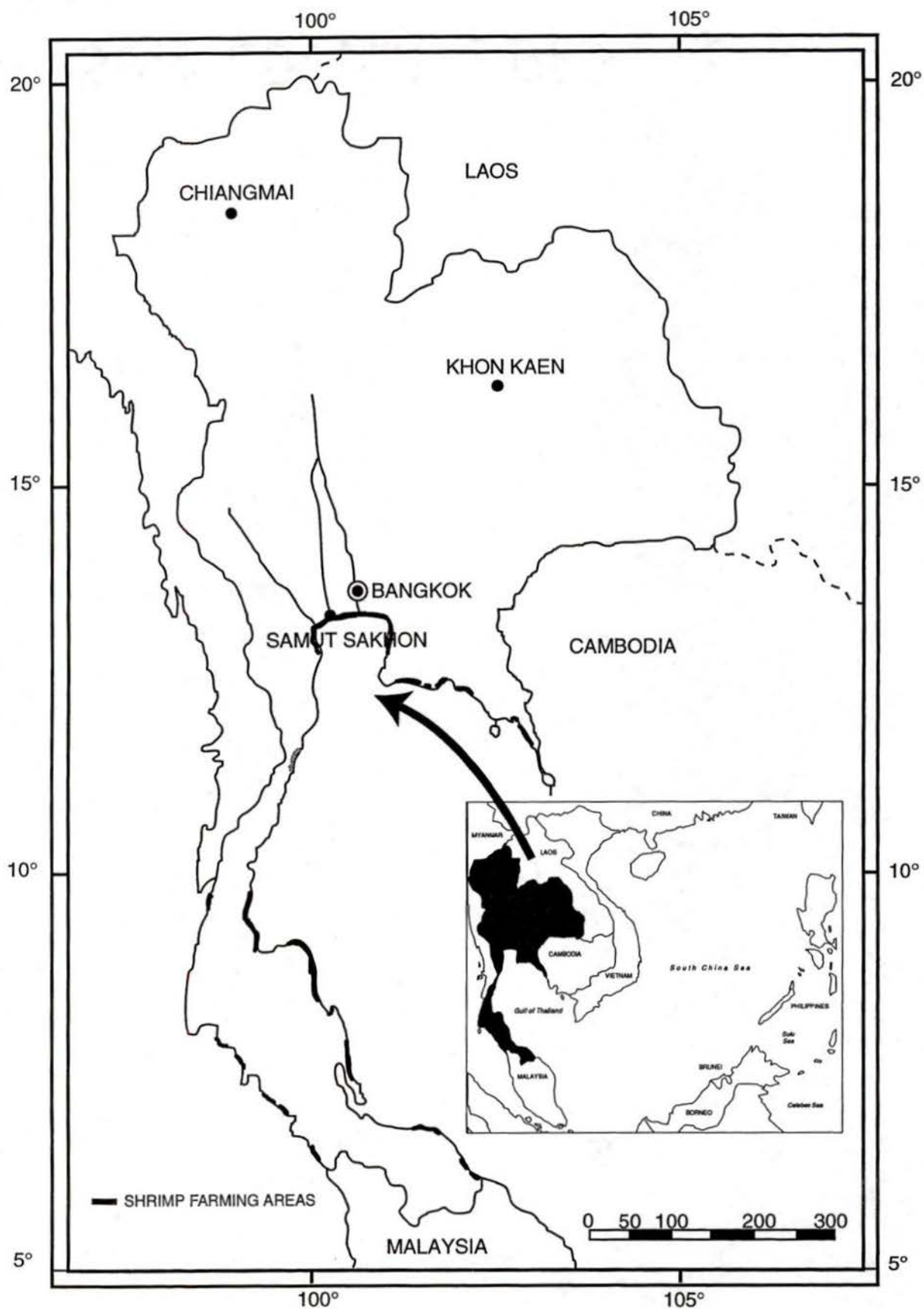


FIGURE 4. MAP OF SOUTHEAST ASIA AND THAILAND

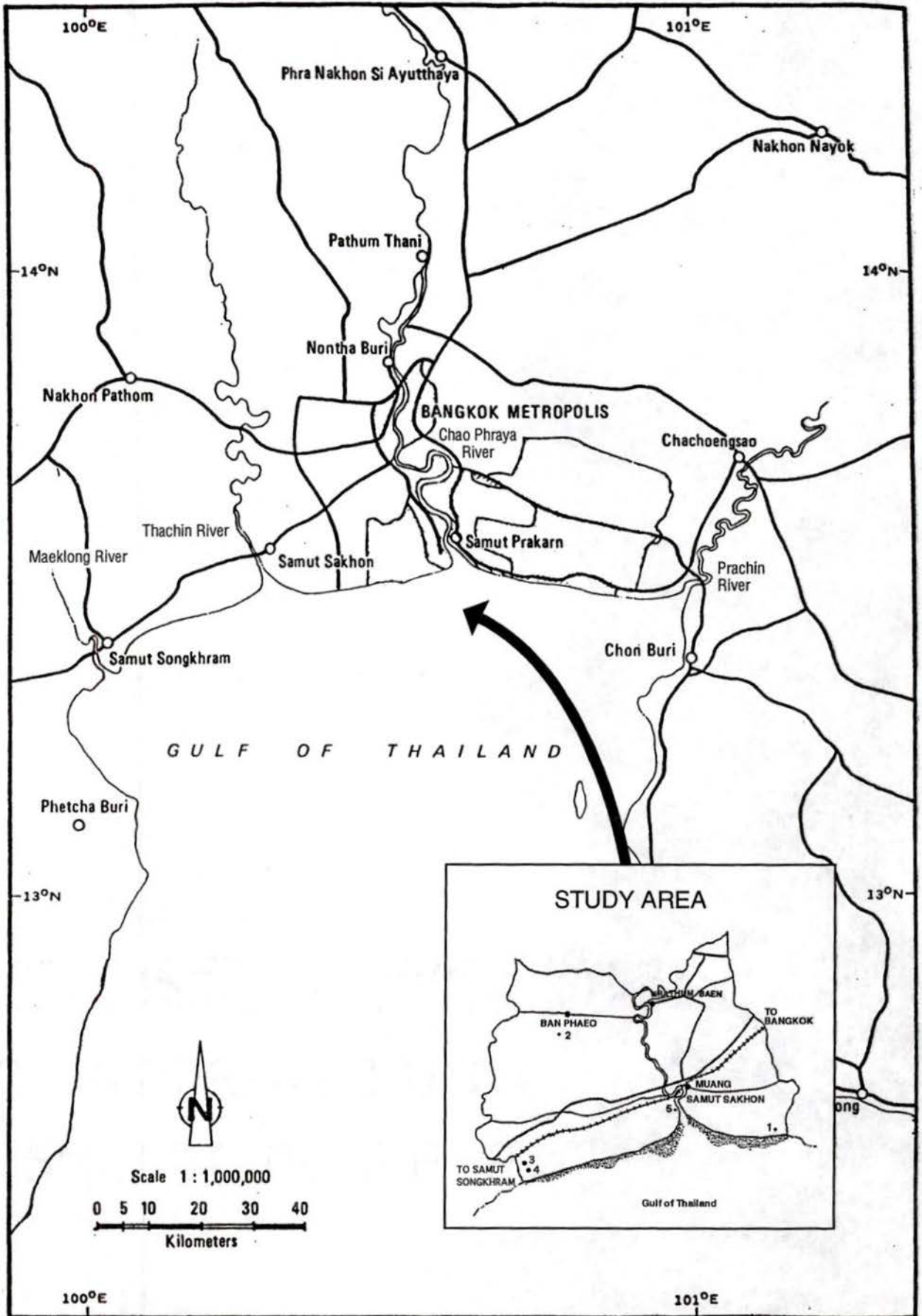


FIGURE 5. MAP OF THE UPPER GULF OF THAILAND

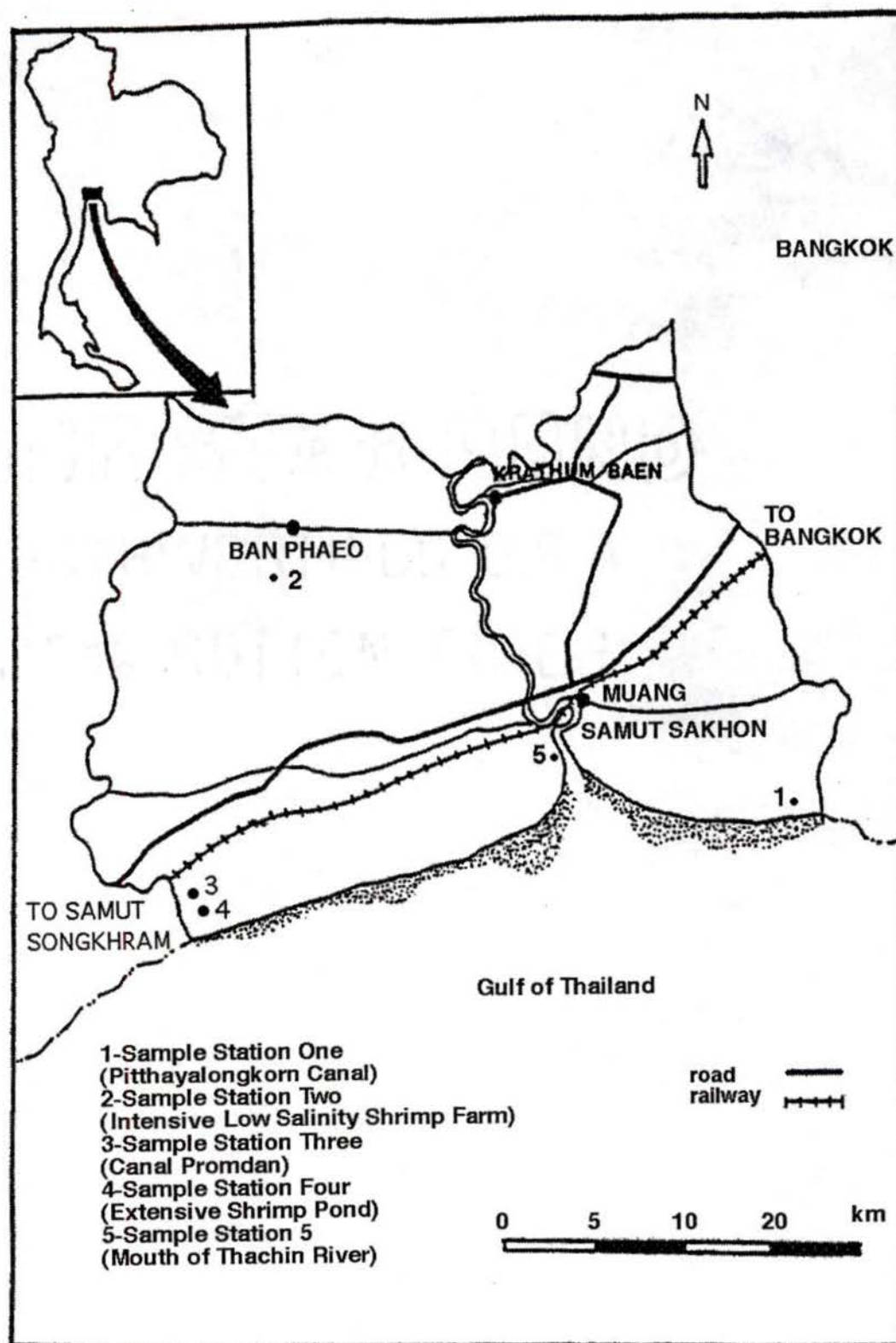


FIGURE 6. MAP OF THE PROVINCE OF SAMUT SAKHON
INDICATING FIELD SAMPLE STATIONS

2.2 Biophysical overview of the study region

This section presents a biophysical description of the case study region with emphasis on the characteristics that relate to the activity of shrimp farming. Thailand has many advantageous and sometimes unique features favoring the development of shrimp farming. These include a favorable climate, temperature, humidity, rainfall, and tidal characteristics, a lengthy coastline with access to sufficient quantity of the various water resources required for shrimp farming. Other important unique locational aspects include: the lack of typhoons or cyclones, ideal and unchanging water temperatures and ideal soils and terrain for pond construction (Ferdouse, 1990; Liao, 1990; New, 1991 and Menasveta, 1992). The salient physical, chemical and biological characteristics of the coastal areas of the province define the level and type of aquaculture that can be sustained.

2.2.1 Geography and topography

The province of Samut Sakhon is located in the central plain most of which is in the Lower Chao Phraya Basin. The sediment transported from the Ping, Wang, Yom and Nan river basins in the north, and from the watersheds in the east and west results in siltation in this plain. Deposition from these sources forms the largest plain in the country with a width and length of 175 km and 450 km respectively. The central region is flat and surrounded by mountain ranges except in the south where is connected to the Gulf of Thailand.

Samut Sakhon is generally a lowland coastal plain comprised of two main land form classes: the active tidal flats and former tidal flats with recent marine and brackish water deposits. The southern part of the province is primarily low lying and parallel to the coast and represents the areas used for salt making and shrimp farming. The eastern and western regions are a sea water flood plain and the central part of the province is divided by the Thachin river are low land. This area is flooded during the rainy season and used for rice paddy farming. The upper regions are generally, but not exclusively, utilized for agricultural purposes assisted by a network of natural and man made canals. With respect to river systems the Thachin river which runs from north to south through the center, the Chao Phraya river is located to the east and the Mae Klong River to the west. The river systems are important to all land uses and are the eventual

recipients of precipitation runoff and effluent from all activities. All of these rivers empty into the Upper Gulf of Thailand.

2.2.2 Climate, temperature, humidity and rainfall

The climate of the study region is tropical Savannah distinguished by wet and dry seasons with high temperatures throughout the year. The climate, dominated by the southwest and northeast monsoons, can be divided into three distinct seasons (ESCAP, 1992). These seasons are influenced by monsoon winds that create wet and dry conditions and the transition periods between each (i.e. wet to dry and dry to wet). The wet season usually occurs between May and January in association with the southwest monsoon. The dry season occurs between February and April.

The climate influences the circulation patterns of the Gulf of Thailand. There is a rotating current that flows clockwise in the Gulf of Thailand, its strength varying with season (Figure 7).¹ This finding is supported by Wongwises et al. (1994) who completed a numerical investigation of the current patterns in the Gulf of Thailand. Such reports emphasize the importance of the monsoon winds in controlling the surface circulation and are an important consideration in the siting of aquaculture facilities.

The amount of rainfall in Samut Sakhon is mainly brought by the southwest monsoon and occasionally by depression storms (ESCAP, 1992). Table 2.2 provides the climate information for selected shrimp farming provinces in Thailand from 1982 to 1993. The average annual rainfall in Samut Sakhon during the period from 1982 to 1993 was 1,205 mm with the coastal areas receiving more precipitation. The average annual temperature range was 25 to 29 °C and the relative humidity varied from 72 to 76% (OEPP, 1994b). For comparison, information from other coastal shrimp farming provinces, namely Chanthaburi and Nakhon Si Thammarat provinces is included. These factors are important considerations influencing the decisions made with respect to ongoing shrimp culture operations.

¹The tidal circulation patterns of the Gulf of Thailand depicted in Figure 4 are based on Wyrski (1961) who characterized the tidal types of the Southeast Asian waters.

Table 2.2 Climate information for selected coastal shrimp farming provinces in Thailand from 1982 to 1993 (OEPP, 1994b)

Province	Average annual rainfall (mm)	Temperature (°C)	Relative humidity (%)
Chanthaburi	2,925	24.3-29.4	64-86
Nakhon Si Thammarat	2,292	25-29	69-90
Samut Sakhon	1,205	25-29	72-76

2.2.3 Tidal period and range characteristics

The coastal bed of Samut Sakhon is a muddy flat with a slope of about 1%. The tidal periods are mixed between a single and a diurnal tide experiencing two low tides and one high tide per day. The tidal range determines the various shrimp farm features such as depth of the pond bottom, size and height of the perimeter dike to prevent flooding, the slope ratio and the drainage systems of the shrimp farm. The direction and strength of water current should also be known for provisions on dike construction to reduce bank erosion. Table 2.3 provides the tidal characteristics recorded in the province of Samut Sakhon at Tambol Maha Chai in 1992 and 1993 which found the highest high water was +1.23 meters in January and the lowest low was -0.83 meters in July (Meteorological Department, 1994). The current during the tidal flow was northwards during a high tide and southwards during a low tide at a flow rate ranging from 2.70 to 3.70 km/hour.

Table 2.3 Average tidal range (m) at Tambol Maha Chai in the province of Samut Sakhon from 1992 to (Meteorological Department and cited in OEPP, 1994b)

Month	1992		1993	
	Average high water	Average low water	Average high water	Average low water
January	1.23	-0.29	1.23	-0.26
February	1.19	-0.36	1.20	-0.37
March	1.16	-0.33	1.20	-0.27
April	1.12	-0.31	1.13	-0.28
May	1.01	-0.34	1.03	-0.31
June	1.04	-0.42	0.86	-0.53
July	1.02	-0.54	0.80	-0.83
August	1.01	-0.64	0.87	-0.75
September	1.09	-0.61	-	-
October	1.16	0.25	-	-
November	1.17	-0.08	-	-
December	1.12	-0.13	-	-

Note: Tidal range in meters, estimated from medium sea level.

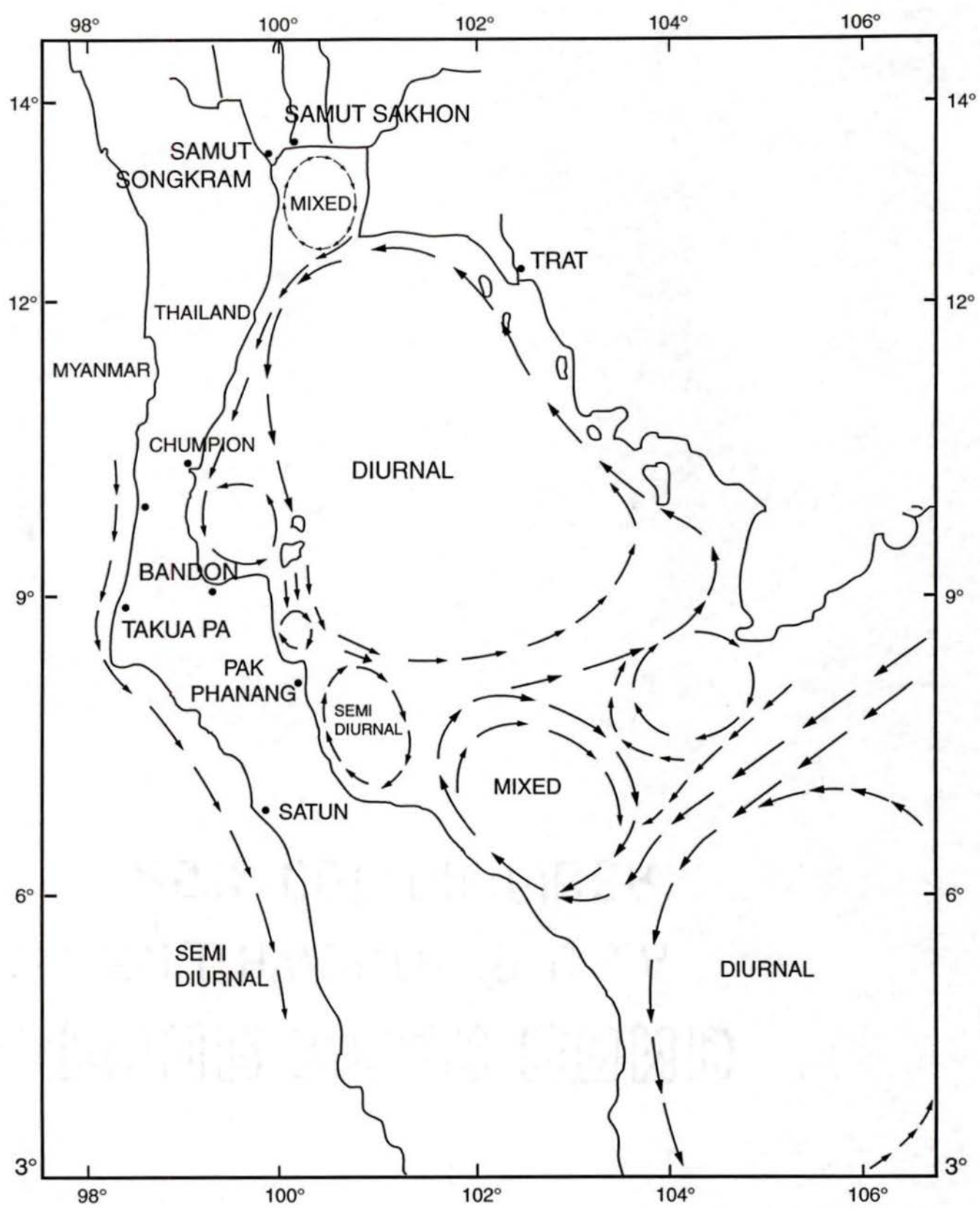


FIGURE 7. TIDAL CIRCULATION PATTERNS OF THE UPPER GULF OF THAILAND (USING INFORMATION ADAPTED FROM WYRTKI, 1961)

2.2.4 Length of coastline

Shrimp farms in Thailand, primarily coastal operations, utilize some of the total 2,614.40 kilometers of coastline which includes 1,874.80 km along the Gulf of Thailand and 739.60 km along the Andaman sea (Hungspreugs et al. 1989). The total length of coastline of the Upper Gulf provinces is 366.8 km. Table 2.4 provides the length for each of the Upper Gulf provinces and other shrimp farming areas of Thailand for comparison.

Table 2.4 Length of coastline for Upper Gulf provinces and other major shrimp farming areas of Thailand (Statistical Yearbook of Thailand, 1989)

Province	Length of coastline (km)
Chonburi	156.80
Chachoengsao	12.20
Samut Prakan	47.20
Samut Sakhon	38.80
Samut Songkhram	21.20
Phetchaburi	90.60
Upper Gulf Total	366.80
Gulf coast and pacific coast	1,874.80
Indian Ocean	739.60
Total	2,614.40

2.2.5 Water bodies

The Gulf of Thailand is the ultimate receiving water body of the effluent through direct discharge or from riverine inputs from the many intensive coastal shrimp aquaculture farms, in addition to the stresses from many other multi-purpose uses. The Gulf is a shallow arm of the South China Sea constituting a portion of the Sunda Shelf. The Gulf is situated on an axis tending roughly north-northwest between latitude 5°00' to 13°30' north latitude and longitude 99°00' to 106°00' east. The Gulf is approximately 720 km long with a maximum depth of 85 meters along and may be characterized as a classical two-layered, shallow-water estuary (Robinson, M.K., 1963). The Gulf is bounded on the east, north and west by the coastline of Vietnam, Cambodia and Thailand respectively, and on the south it connects with the South China Sea. The total area of the continental shelf up to 200 m depth is estimated at 30,500,000 ha.

The Gulf, being roughly triangular in shape, is divided into two sections designated as the "upper gulf" and the "outer gulf". The upper gulf is the roughly square shaped apex of the Gulf of Thailand. The surface area of the Upper Gulf is about 1,036,000 ha with an average depth of 20 meters and a slope of about 0.2 meters/km. The Upper Gulf receives the run-off from the following six principal tributary rivers after flowing through the study region: Chanthaburi, Bang Pakong, Chao Phraya, Thachin, Mae Klong and Tapi rivers. The Chao Phraya is the largest and receives the upland inputs from the Bangkok Metropolitan Region.²

2.2.6 Ground and surface water resources

The water resource budget for any shrimp farm operation draws on both fresh and salt water supplies. These include precipitation run-off and a mixture of freshwater (e.g. surface water and ground water extracted from aquifers) and saltwater sources (i.e. Gulf of Thailand or the Andaman Sea). The surface and ground fresh water supplies are abundant since the area occupies a relatively broad flood plain with a drainage basin that yields large quantities of surface runoff, especially in the rainy season. The Thachin river is the main source of area water supply and separates from the northern Chao Phraya river at Ban Park Klong Makam Chao, Chainat province and flows south through the middle of the province emptying into the Upper Gulf of Thailand.

There are four canals supplying freshwater to the Thachin with the water salinity being less than 6 parts per thousand (ppt). This characteristic is important as the water salinity for general plant growth is 6 ppt and the salt tolerant saline Nipa palm grows on a narrow strip up both river banks up to 6 kilometers from the river mouth (Popan, 1994). In most cases the availability of fresh and saline water sources determines the mixture utilized by a particular operation. The water salinity preferences for shrimp farming are changing as shrimp farms now use a wide salinity range from near freshwater to full strength sea water. This "industry preference" for salinity has an effect on the quantity of water consumed, type of delivery system utilized and the resulting environmental impacts.

² The Chao Phraya river is one of the most important rivers of Thailand and covers a large basin area of about 162,000 km². It originates from the mountain ranges in the north and covers nearly all the areas in the Northern and Central regions. The major tributaries of the Chao Phraya are the Ping, Wang, Yom and Nan rivers. The river flows from the northern valley through the central plain and into the Gulf of Thailand.

Ground water resources: Ground water resources are an important source of water for all activities, including shrimp farming, particularly in the central plain, near the region of study. The quantity and quality of ground water varies according to local hydrogeological conditions (e.g. shallow or deep water aquifers). In some areas ground water is the only source utilized for shrimp culture operations which may create an increased demand for freshwater with the potential to outstrip available supplies, especially during the dry season. In Samut Sakhon, there are two categories of ground water aquifers. The extensive and productive Category One aquifers are found in the porous rock of the lower central plain under the Bangkok clay at a depth ranging from 50 to 550 m. The various sub-aquifers and associated depths are: Bangkok (50 m), Phra Pradeang (100 m), Municipal (150 m), Nonthaburi (200 m), Sam Kok (300 m), Phraya Tahi (350 m), Thonburi (450 m) and Pak (550 m). The Category Two aquifers are the southern plain porous stone that is scattered underground ranging from 10 to 200 m depth and discharges at a rate of not more than 10 gallons/min (OEPP, 1994b).

Surface freshwater resources: Ample quantities of surface freshwater are available to shrimp farmers in the study region. The study region, is dominated by the extensive flood plain of the Chao Phraya river. The central region has a total river basin drainage area of 73,459 km² with an annual runoff of 23,910 mcm/yr. Table 2.5 provides the river basins, drainage areas and long-term average run-off volumes the different regions of Thailand. This information for the central region is provided in greater detail. Information for the other regions is provided for comparison to this central region.

From the country's average annual rainfall of about 1,485 mm or 761,700 million m³ equivalent, the resulting surface run-off after subtracting losses such as evaporation, transpiration and infiltration is about 198,791 million m³ or about 26 % of the rainfall. The surface run-off is drained mainly to the Gulf of Thailand. This value is significant as most rivers have a highly concentrated flow during the southwest monsoon period during which 80 to 90 % of the annual flow occurs. To combat this irregular water flow, irrigation projects have been set up in agricultural areas throughout the country (ESCAP, 1992) including the province of Samut Sakhon.

Table 2.5 Surface water resources of Thailand (NWRC, 1990)

Region	River Basin Name	Drainage area (km ²)	Annual runoff (mcm/yr)
Central	Lower Chao Phraya	20,125	4,925
	Sakae Krung	5,191	519
	Pasak	3,625	2,708
	Thachin	13,681	2,815
	Mae Klong	30,837	12,943
	Central Region Total	73,459	23,910
North	Salawin, Mekong, Kok Ping, Wang, Yom, Nan	148,868	34,440
Northeast	Chi, Mun	168,846	43,469
East	Prachinburi, Bang Pakong, Rayong, Phetchaburi, Chumphon, Tapi	36,448	21,218
South	Pattani, Trang	84,450	75,660

Note: mcm/yr = million m³/yr

2.2.7 Seasonal variation in regional water quality

Shrimp farm performance is affected by seasonal water salinity changes. Such changes are important considerations in establishing field sampling and monitoring programs. Salt water intrusion determines the quality of the water in the province. The freshwater supply from rainfall and from the Chao Phraya and Mae Klong rivers controls the extent of sea water intrusion up river. The salinity profile is characterized as a moderately stratified estuary pattern in which the more dense sea water flows along the bottom of the estuary. In April, at the height of the dry season, sea water flows upstream a further 10 km under both high and low tide conditions. However, sea water flows up the river for only 4 km in the low tide condition during the late rainy season in August. In December, the water quality pattern is intermediate between these two extremes. The salinity pattern has an effect on the supply of water to the shrimp farms.

The river Biological Oxygen Demand (BOD) is subjected to slight variations according to both discharge of sewage and industrial effluents and the degree of dilution. Seasonal climatic conditions, particularly rainfall, and the supply of river water from upstream affect dilution. The highest BOD occurs at 4 to 6 km from the river mouth at Samut Sakhon city and exhibits the same pattern for both rainy and dry seasons. The BOD value of the Thachin river is slightly higher than the Maha Chai and Damnoen Saduak canals, perhaps due to fish and shrimp farms. The Phasi Charoen canal which passes

through a horticultural area has the lowest BOD and ranges from 1.4 to 3.7 mg/L. The dissolved oxygen (DO) values show the adverse effect of BOD. The sea water has a higher DO than fresh water. Four to six km from the river mouth has the lowest DO. Although there are 1,291 factories located on either side of the Thachin, the COD is lower than 32 mg/L (Popan, 1994). Further reference and discussion to both the existing water quality in the region and that required by shrimp farms will be presented in Chapter 2 below.

2.3 A brief description of shrimp culture: aquaculture management systems and methods

Most aquaculture operations in Asia consist of pond based systems for shrimp and fish. The management strategies for shrimp culture are categorized into different methods: extensive (or 'traditional'), semi-intensive, intensive and super-intensive. These distinctions are based on the following: capital costs, energy, consumption, material use (e.g. seed, food, fertilizer and chemicals), labor requirements, technology input and productivity. The representative features of aquaculture management systems can be illustrated according to the scale and nature of operation, the relative amount of control over environment and the ability to manipulate production. These factors then dictate the amount of interaction between the aquaculture system and the environment. Table 2.6 presents the comparative features of the various aquaculture management systems. The suitability and selection of the various methods of grow-out intensity depend on environmental and social factors linked to natural resource availability and will be discussed below.

Table 2.6 Comparative features of various methods of shrimp culture (Saenger, 1993)

Feature	Traditional or Extensive	Semi-intensive	Intensive
Pond size (ha)	30.0 (Traditional); 5+ (Extensive)	1-8	<0.5
Stocking density/ha	20,000	80,000	300,000
Fry source	Wild	Wild/Hatchery	Hatchery
Crops per year	1-2	2-3	2+
Survival (%)	50	70 to 80	70 to 80
Minimum water depth (m)	<1.00 (Traditional); 1.00 (Extensive)	1.10	1.20
Aerators per hectare	None	4-8 units	4-8 units
Feed Source	Natural	Natural/ Supplement	Artificial
Water management	Tidal exchange	Tidal/Aerators	Pumps/Filters
Effluent volume	Large	Smaller	Least
Effluent quality	Acceptable	Poor	Variable
Production (kg/ha/year)	200 to 400	1000	4000 to 8000

2.3.1 Extensive aquaculture systems

Extensive culture is a low density, tropical aquaculture method that relies solely on the provision of natural food supply through tidal water exchange and, in some cases, minimal supplementary feeding and pesticide use.³ The shrimp feed on naturally occurring organisms which are occasionally supplemented with natural organic or commercial fertilizers. The tides generally provide a water exchange rate of about 5 % to 10 % per day. The shrimp are sequestered in natural or man made impoundment's that range in size from a few hectares up to a hundred hectares. When local waters are known to have high densities of young shrimp, farmers open the gates, impound the wild shrimp and then grow them to maturity. Fishermen also capture wild juveniles and sell them to extensive shrimp farmers for stocking. The cultured organisms are normally natural food organisms and are kept at low densities, about 20,000 post-larvae/ha. The technology that is used tends to be relatively simple, requiring low-capital investment and operating expenditures, using largely unskilled household labor. In many cases the operations are single family operations. While construction and operating costs are low so are the yields. Cast nets and bamboo traps produce a harvest of 50 to

³ The 'extensive' system is sometimes referred to a the 'traditional' system. Differences between the two are noted in Table 2.1.

500 kilograms (head-on) per hectare per year. Production costs range from \$US 1 to 3 /kg of live shrimp (Rosenberry, 1992).

2.3.2 Semi-intensive aquaculture systems

Semi-intensive culture methods involve stocking the organisms at higher densities than extensive systems. Conducted above the high tide line in supra-tidal areas, semi-intensive farming introduces a nursery phase, pre-constructed grow-out ponds ranging from 1 to 8 ha, commercial feeds and pumping. Pumps exchange 10 % to 20 % of the water per day and some natural tidal flushing is utilized. Farmers renovate their ponds between crops. With stocking rates of up to 80,000 post-larvae/ha, there is more competition for the natural food in the pond, so farmers augment production with shrimp feeds and fertilization techniques. Production yields range from 500 to 5,000 kilograms (head-on) /ha/yr, with 2,000 kg/ha/yr a much sought after goal. The farmer harvests by draining the ponds through a net attached to the pond discharge outlet. Construction costs range from \$US 15,000 to 25,000/ha. Production costs ranges from \$US 3 to 5/kg of live shrimp (Rosenberry, 1992).

2.3.3 Intensive aquaculture systems

Intensive shrimp culture methods utilize small enclosures ranging from 0.1 to 5 ha, high stocking densities with artificial fry sources ranging from 300,000 juveniles/ha, continuous management, involving heavy feeding, waste removal and aeration. The addition of air, or oxygen to the pond water by aeration allows for much higher stocking and feeding levels. Most frequently conducted in small outdoor ponds, it is also practiced in raceways and tanks, which may be covered or indoors. Construction costs range from \$US 25,000 to 100,000 /ha. Production costs ranges from \$US 5 to 7/kg of live shrimp (Rosenberry, 1992). Shrimp are generally harvested, if there are no disease problems, when they achieve a mass of 30 pieces/kg of live weight (head-on). The crops are regularly sampled to discern this statistic. The present report involved direct field observation and sampling of an intensive shrimp farm in the province of Samut Sakhon (Sample Station 2). The information from these observations will be presented in Chapter 5. Figure 8 portrays a typical intensive shrimp farm in operation. Figure 9 portrays a healthy black tiger shrimp.



FIGURE 8. A TYPICAL INTENSIVE SHRIMP FARM IN OPERATION. AERATORS ARE POSITIONED AND OPERATING TO MANIPULATE SEDIMENT ACCUMULATION AND IMPROVE WATER QUALITY



FIGURE 9. FULL GROWN HEALTHY BLACK TIGER SHRIMP (*PENAEUS MONODON*)

2.3.4 Super-intensive aquaculture systems

Still experimental, 'super-intensive' shrimp farming involves even greater control of the environment and can produce yields of 10,000 to 100,000 kg/ha/yr. Thailand currently has many experimental super-intensive shrimp farms which have thus far, only achieved marginal success. They generally have the most pronounced problems with respect to management, disease, water quality and the environment. This culture method has been reported by several researchers (e.g. Yano, 1993; Moore and Brand, 1993). There is little information on the current state of the super-intensive shrimp farms in Thailand and the Upper Gulf region.

2.4 Biophysical resource input requirements of Thai coastal shrimp aquaculture operations

The set of natural resources critical to the success of land-based intensive coastal shrimp aquaculture operations are as follows: land, water, labor, fry and food (i.e. fertilizers, manure, and supplementary feed) (Table 2.7). These inputs are all considered in this section.

Table 2.7 Physical and biological (biophysical) resources required for Thai coastal shrimp aquaculture operations

Land: siting of farms and associated infrastructure (i.e. ponds)

Water: essential for aquaculture (quality and quantity)

Feed*: nutrition of the cultured crop in grow-out pond

Seed*: obtained from capture or culture fisheries for stocking grow-out pond

Note: * 'Fry' and 'food' are the biological resources designated by the industry for commercial purposes as 'seed' and 'feed' respectively.

The degree of intensification is determined by the availability of *natural resource capital* and ultimately determines the yield per unit area of production utilized (Hepher, 1985). Most resource-dependent industries typically manage the fundamentally required biological and ecological systems as if they were incidental to society (Davis and Simon, 1995). The activity of shrimp farming is no different. It is well known that the use of

natural resources for enterprise may lead to profitable economic gain, or if badly planned and managed, to irreversible environmental damage. Lost opportunities and rehabilitation costs can easily lead to net economic loss (Odum and Arding, 1991). Thus, the nature of the resources available and the manner in which they are used play a key role in the economic success and particularly the sustainability of shrimp farming. Shrimp farm operations consume natural resources in a manner that exceeds ecological limitations (or carrying capacity) and appropriates a disproportionate share, well beyond the borders of the shrimp farm.

These considerations led the author to conclude that the level of biophysical resource appropriation of shrimp farms is a critical factor. The level of resource appropriation is further discussed in the sustainability analysis in Chapter 6.

2.4.1 Land

The appropriation of surrounding land affects the areas used for shrimp farming and is directly linked to land availability and competition with other coastal users. The type of land used for shrimp farming has an effect on the success of shrimp farming itself, environmental impacts and conflicts with other coastal resource users and dwellers. Shrimp farms in Samut Sakhon have been constructed on a variety of coastal lands, including salt pans, areas previously used for agricultural crops, such as rice, sugar and coconut, abandoned and marginal land, and former mangrove wetlands.

Figure 10 presents the area of the designated land use types for the province of Samut Sakhon by sub-district in 1992.⁴ The land uses were as follows: urban, agriculture, shrimp, salt farm, mangrove and 'swamp and idle'. The traditional preference for low-lying coastal wetlands for the construction of shrimp ponds has changed to the industry preference for *supra-tidal land* where ponds are cheaper to construct, and soil drainage is normally better.⁵ The land requirements of culture ponds vary according to the type of aquaculture system. Intensive ponds are generally less than 0.5 ha each, semi-intensive ponds range from 1 to 8 ha, extensive ponds are generally greater than 5 ha. Traditional pond systems in some cases utilize ponds greater than 30 ha each (Table 2.1). Figure 11 presents the designated land use types for Samut Sakhon determined by satellite image (Popan, 1994).

⁴ Determined from a 1992 remotely sensed satellite image of the province by Popan (1994).

⁵ *Supra-tidal land* utilized for shrimp pond construction is defined as upland sites above the influence of tidal regimes.

2.4.1.1 Number of shrimp farms and area cultured

The increase in cultured shrimp production is driven by both an increase in the number of shrimp farms and the total farm area (Figure 12). The increase in productivity of existing units through intensification of methods adds further to the production increases. Between 1976 and 1991 the area covered by shrimp farms increased at 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 12,296 ha (NACA, 1994); by 1994 there were 80,000 ha, divided into around 20,000 farms (Anon., 1995b). In 1992, the combined fish and shrimp pond area in Samut Sakhon were 29,479 ha.

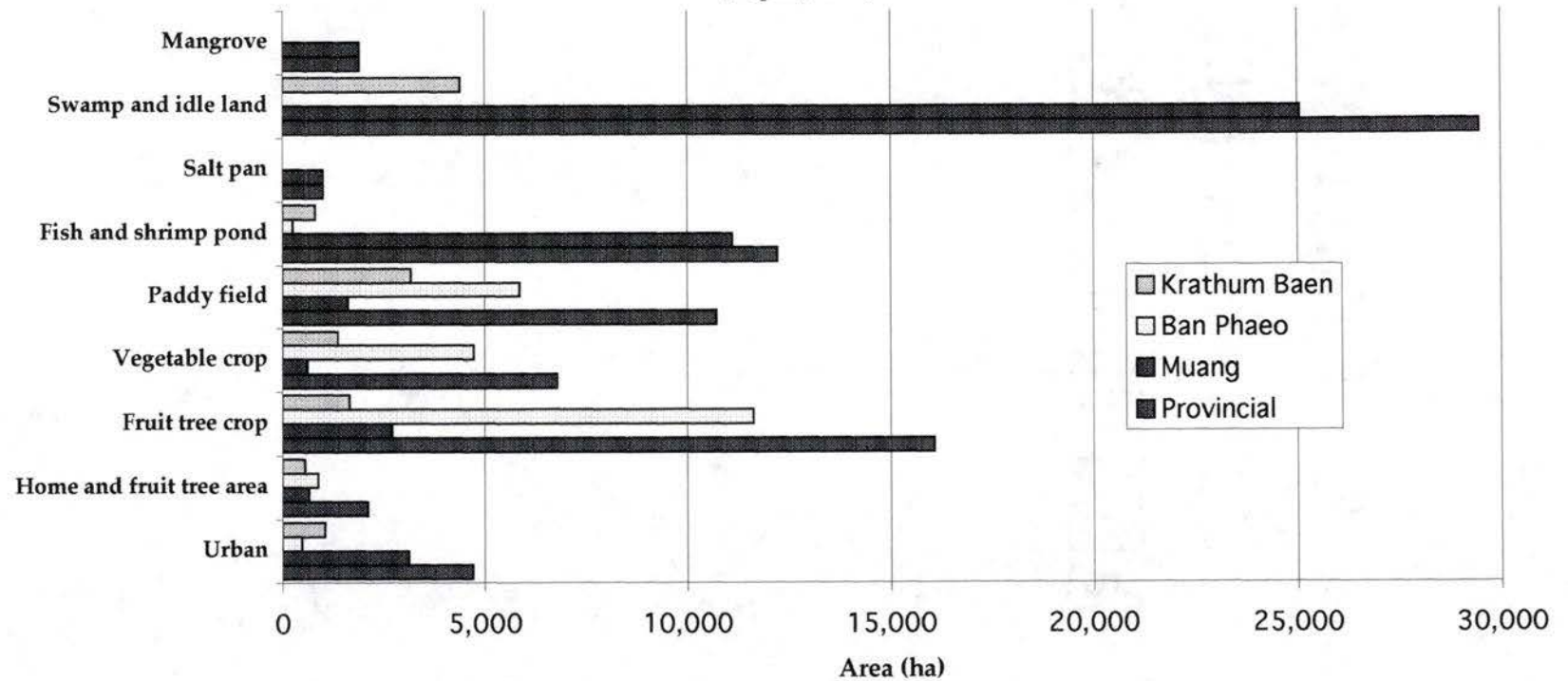
2.4.1.2 Regional distribution and size of intensive shrimp farms

Intensive shrimp farming operations have now been established in the majority of the coastal areas in Thailand (Table 2.8). The eastern and southern coastal provinces are now the most heavily utilized regions for shrimp farms. The farms in these areas are located in most easily exploitable and accessible coastal areas. Nearly 80 % of these intensive farms are small-scale operators with 1 to 2 ponds each from .16 to 1.6 ha apiece. Although these new shrimp farming areas are said to have access to more favorable water quality conditions they are not immune to pollution problems. Currently, 51 % of the total number of farms in Thailand use intensive methods, 21 % use semi-intensive and the remaining 28 % traditional extensive methods. Intensive farms produce 90 % of the total cultured shrimp harvest (NACA, 1994).

Table 2.8 Number, size and geographical distribution of intensive shrimp farms in Thailand (CP Technical Extension Service, 1991; Asian Shrimp News, 1992)

Farm size (ha)	Eastern	Central	Southern	Total	%
0.16-1.6	2,801	811	6,271	9,883	78.7
1.6-8.0	1,801	373	945	2,363	18.8
8.0-32.0	17	5	14	36	0.3
>32.0	17	5	14	36	0.3
Total	4,012	1,256	7,293	12,561	100

Figure10. Area of designated land use types and area (ha) in the province of Samut Sakhon in 1992
(Popan, 1994)



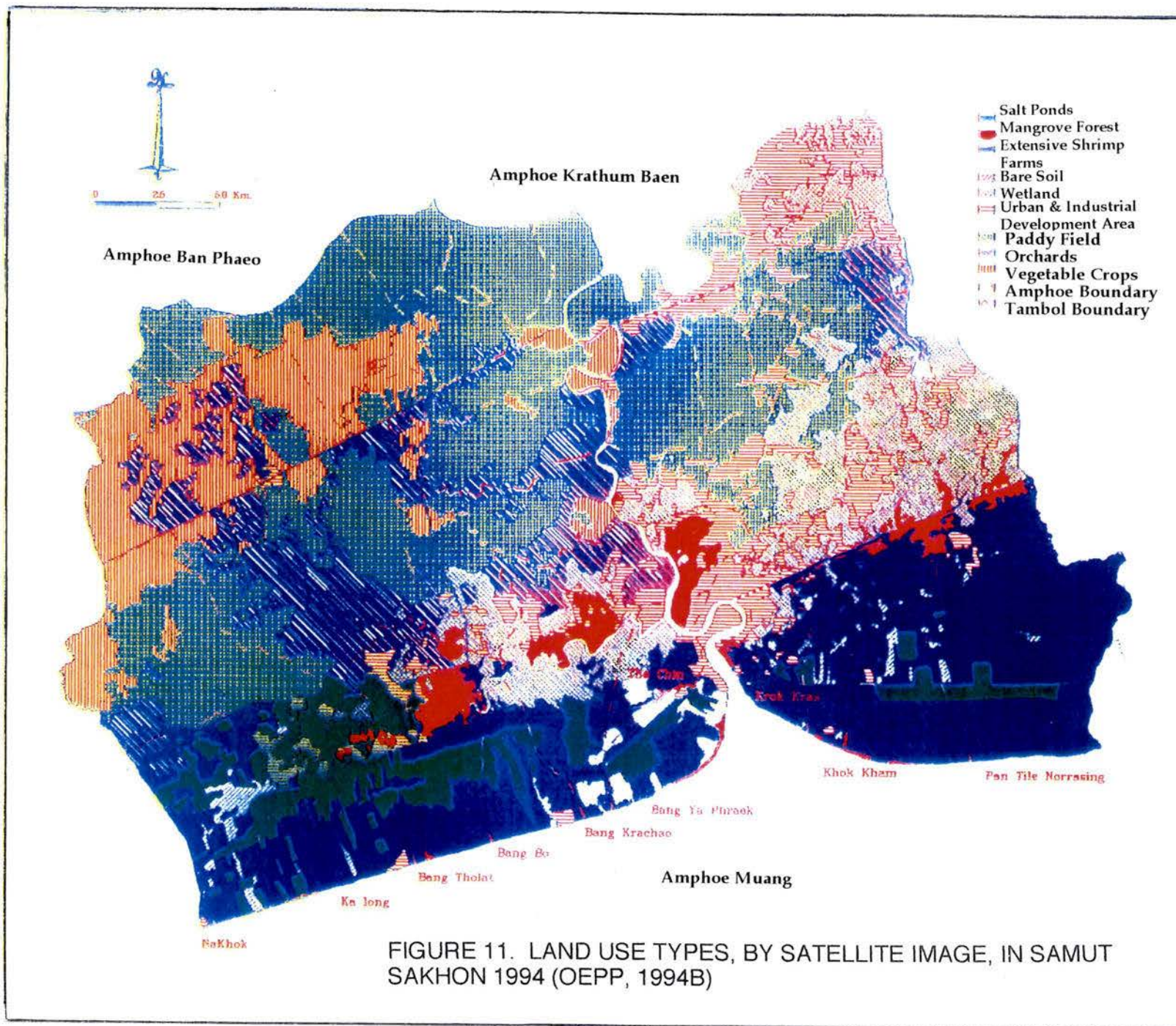
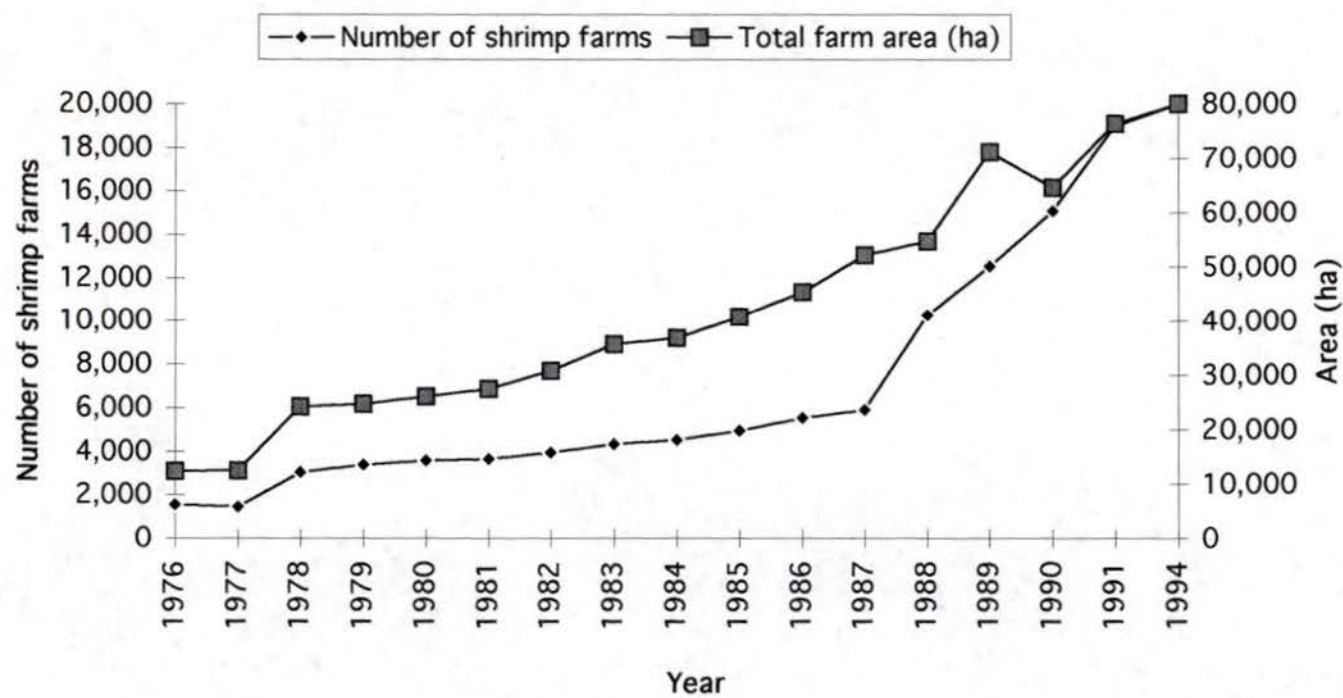


Figure 12. Number and area of shrimp farms in Thailand from 1976 to 1990 (NACA, 1994) and for 1994 (Anon., 1995b)



2.4.2 Water

Currently, aquaculture is a net consumer of water and most culture systems require the use of considerable quantities (Muir and Beveridge, 1987; Phillips et al., 1991). Water exchange replenishes dissolved oxygen (DO), dilutes harmful wastes and regulates salinity levels (Apud et al., 1983). The quality and quantity of water used for shrimp culture is a critical factor affecting the sustainability of the industry. Water quality is crucial during the early life stages in the hatchery and during the grow-out period in the ponds. Most practical handbooks (i.e. Strickland and Parsons, 1972; Stirling, 1985; Boyd, 1992; Chapman, 1992 and Davis and Simon, 1995) recommend that water used for shrimp culture should be free from agricultural, domestic and industrial pollution, and be within specified salinity and temperature ranges (Apud et al., 1989). However, increasing urbanization, industrialization and chemical use in agriculture makes it extremely difficult to find such pollution-free waters in many coastal areas. Huguenin and Colt (1989) suggest preliminary water quality screening and appropriate production levels for marine applications.

The quantity of water required for shrimp culture operations has its own set of implications for sustainability. The amounts required for shrimp hatcheries are small compared to the amounts required for the ponds (Phillips et al., 1993). The total amount required depends on the nature of the shrimp culture system and is similar to the land requirement. Although extensive culture systems require more, on a total water volume basis, they require less 'replacement' water. Total replacement water demand increases with the need to flush away metabolic wastes associated with more intensive management practices. The water requirements for shrimp culture, general and specific, and other forms of aquaculture have been compiled by various sources (Table 2.9). For example, the amount of water required for each metric tonne of shrimp produced in Taiwan is 29,000 to 43,000 m³ in intensive systems compared to only 11,000 to 21,430 m³ in semi-intensive culture. Estilo (1988) calculated the total water requirements of a shrimp farm over one cropping period. In order to maintain a pond salinity of 15 ppt with a water exchange rate of 30 % per day for a 7 ha farm with 1 meter deep ponds 9000 m³ (1300 m³/ha) of 35 ppt sea water and 112,000 m³ (16,000 m³/ha) of freshwater is required. While such data is useful for indicating the scale, practices are site specific and variable. To obtain fresh water, shrimp farmers prefer underground aquifers to river sources which may carry agricultural and industrial pollutants.

Table 2.9 Water requirements of extensive, semi-intensive and intensive shrimp culture systems as compared to other forms of aquaculture

System	Production (MT/ha)	Water use (m ³ /MT)	References
<i>General</i>			
Extensive ponds*	0.3 - 0.8	44,000-233,000	Edwards et al., 1987
Semi-intensive ponds	1.0 - 5.0	7,000 - 70,000	Muir, 1981; Sarig, 1989
Intensive ponds	3.0-8.0	4,000-23,000	Hepher, 1985
<i>Specific</i>			
Semi-intensive Penaeid shrimp ponds (Taiwan)	4.1-11.0	11,000-21,430	Wickens, 1986; Chien et al., 1986
Intensive Penaeid shrimp ponds (Taiwan)	12.6-27.4	29,000-43,000	Wickens, 1986; Chien et al., 1986
Salmonids (U.K.)	-	252,000	Solbe, 1987
Clarias batrachus	100-200	50-200	Muir, 1981
Common Carp	1,443	740,000	Hepher, 1985

Note: * With respect to the general entries, the estimated values for extensive, semi-intensive pond culture assume a mean pond depth of 1 m during the growing season, water losses of 1 to 2 cm/day and 350 days of production per year.

Most shrimp aquaculture operations operate as open systems in all respects and the total water requirements of intensive shrimp farming operations can easily outstrip supply in areas with poor tidal flushing or limited water availability. Water is required for the farm grow-out ponds to replace evaporative and seepage losses and to flush away excess feed and metabolic products from shrimp grow-out operations. The development of various 'closed-cycle' or internal purification systems has led to a trend in some regions towards reduced dependency on replacement water in intensive systems (OEPP, 1994b). In addition, preliminary or pre-treatment of water before use in the shrimp farming operations has become standard operating procedure for Upper Gulf shrimp farms.⁶ Similarly, post-treatment of water from shrimp farms (i.e. treatment/recovery of products from the effluent) also decreases the overall water budget requirements. This operating procedure allows the discharge from shrimp farms to be re-introduced to the water intake systems. Recently observed developments in Thailand that incorporate some aspects of these innovative operating procedures will be discussed in the sustainability analysis in Chapter 6.

⁶ The main impetus to develop these treatment systems is as a precaution or protective measure against the poor quality of the water available to the shrimp farming operations. The benefit of using pre-treatment in reduced water consumption requirements follows from this.

2.4.3 Seed

The supply of abundant healthy larvae is essential to ensure the continuing growth of the industry particularly since supplies of wild stocks are unpredictable both in terms of quality and quantity.⁷ Figure 13 presents the life-cycle of Penaeid shrimp and introduces the terms relevant for the discussion in this section. At present the shrimp industry in Thailand still relies on the wild shrimp fishery for producing post-larvae (PL) from broodstock.⁸ Though the rearing of broodstock from PL in ponds has been successful for a long time in Thailand, the costs of production are still much higher than using the available wild broodstock for the entire industry requirements. The broodstock are obtained from the Andaman Sea just south of Thailand's border with Myanmar.⁹ Spawners are caught by Thai fishermen and sold to hatchery operators. Some operators buy broodstock and run modified maturation facilities, thereby providing a market for both male and female broodstock. One of the increasingly important factors contributing to the decline of shrimp aquaculture is the reduced availability of post-larval shrimp (Parks and Bonifaz, 1994). Different aspects that make up the 'seed' supply to the Thai shrimp industry will now be discussed as follows: hatcheries, PL (production and quality), nauplii and broodstock.

Hatcheries: According to current government information 488 hatcheries operate in Thailand.¹⁰ Many of these operations are small-scale and produce fewer than 10 million

⁷ Figure 13 presents the life-cycle of Penaeid shrimp and introduces the different terms that will be referred to in this section. The life cycle involves the following aspects: egg, nauplius, protozoa, mysis, megalopa and post larvae. The larval stage of *P. monodon* consists of 6 nauplius, 3 protozoa, 3 mysis and 3 or 4 megalopa sub stages, and the time required for each stage are about 1.5, 5, 4-5, and 6-15 days respectively. The protozoa and mysis are collectively referred to as zoea. Furthermore, the megalopa as well as earlier juvenile stages are called post larvae traditionally or fry for commercial purposes. The complete life-cycle for *Penaeus monodon* has been duplicated in hatchery facilities. However, such hatcheries in order to propagate fry or post larvae for shrimp pond stocking relies on the capture of gravid or egg bearing females that are used as broodstock. The eggs from these broodstock are then utilized in the hatchery process.

⁸ The Thai tradition and the long-standing government practice of releasing fish and shrimp fry to the natural water resources during important occasions such as Thai New Year, religious days, birthdays, etc., has reduced the problem of broodstock supply. Accidental leakage's from grow-out ponds also release shrimp to natural waters.

⁹ The Colombian shrimp farming industry relies entirely on captured natural broodstock. One of the reasons for accelerated growth of the industry in Thailand has been the increased rearing of broodstock from post larvae in ponds.

¹⁰ In actuality, the number of hatcheries has been said to be around 2,000 (Siri Tookwinas, DOF, 1994).

PL per year. A few large hatcheries are capable of producing 70 to 100 million PL per year. Thailand's total annual demand for PL is approximately 6 billion, with a value of US\$ 36 million, nearly all of which are produced from hatcheries. Presently Thailand has no shortage of *Penaeus monodon* fry, and the hatchery sector is quite competitive. Consequently, the price for PL is among the lowest in southeast Asia, averaging less than \$US 6 per 1,000 PL. Many of the materials for PL production cost very little.

Penaeus monodon Post-larvae (PL): PL in Thailand are produced in virtually any type of container that will hold sea water. Backyard hatchery operations, which need not be located near the sea, are numerous. Such hatcheries usually consist of a 20 to 100 MT sea water storage tank and many small larval rearing tanks. Larval rearing tanks average from 1 MT to 10 MT in volume. Backyard hatchery operators generally produce only PL. They purchase all of the necessary factors, including sea water, nauplii, algae and feeds. Trucks bring sea water to fill the hatchery storage tank on a regular basis for a fee. Algae can be purchased from an algae culture specialist. The shrimp are fed almost any available by-product, including bits of fish and squid that are washed through a fine screen. Egg custard and formulated diets such as "Frippak" are also used. Artemia is used minimally because it is considered expensive. Hatchery survival is highly variable, ranging from 0 to 90 %. The larger scale hatcheries in Thailand are patterned after the Taiwanese hatchery system, using 40 MT concrete tanks with limited water exchange and aeration. These facilities, like the small-scale hatcheries, place a premium on low-cost fry production and little emphasis on fry quality. Survival rates in the large scale hatcheries are also highly variable. The total demand for PL in Thailand is approximately 6 billion per year.

Post-larval quality: Thai farmers place little premium on post-larval quality and will accept PL that are relatively active. Most of the PL produced in hatcheries in Thailand are of similar quality. Unlike the Philippines for example, Thailand has never had enough wild PL available for shrimp farmers to make a comparison. The only concession observed regarding fry quality is that some of the more progressive Thai shrimp farmers operate nursery tanks and stock PL at PL40 to PL50 in order to ensure higher survival rates in their ponds.¹¹

¹¹ PL40 and PL50 refers to the post larvae age at 40 and 50 days respectively.

Nauplii: Once broodstock are transferred to the spawning facilities, they are eyestalk-ablated and placed in 40 MT concrete maturation tanks.¹² While in the tanks, they are fed a minimum diet of mussels, crab and 'trash' fish and are allowed to mature, mate and spawn.¹³ When nauplii are observed, the entire tank is drained to collect them. The nauplii are then either sold or placed directly in larval rearing tanks. Each female shrimp will produce an average of 2 million nauplii within a 4- to 6-week period. The broodstock are then routinely discarded. The maturation diet is given little emphasis because farmers believe that broodstock are discarded before dietary deficiencies will affect nauplii production. The major emphasis is on producing low-cost nauplii. Nauplii are sold for \$US 0.06 per 1,000, and the production cost in this system is said to be less than \$US 0.03 per 1,000. Thailand uses a total of 18 billion nauplii per year, which are valued at US\$ 1.08 million.

Broodstock: Broodstock (spawners) are obtained from the Andaman by Thai fishermen and sold to hatchery operators. Some operators buy broodstock and run modified maturation facilities, thereby providing a market for both male and female broodstock. Females sell for approximately \$US 50 each and need not necessarily be gravid. Males sell for \$US 4 each. The broodstock obtained from the Andaman Sea are among the largest in southeast Asia. Many females weigh in excess of 200 grams. It is not unusual for one of these broodstock to produce in excess of 2 million eggs in a single spawn.

Government regulations: The government currently controls the importation of shrimp species in Thailand. Government permission would have to be obtained to introduce Specific Pathogen Free (SPF) stocks to the country. Importers must apply to import SPF stocks directly to the Director of Fisheries in Bangkok.

¹² The eyestalk-ablation procedure induces maturation in the nauplii production process. This is the current most 'practical' way of inducing maturation and involves unilateral ablation of either the right or left eyestalk of the female. Ablation is done using a razor blade to cut/open the eye, then squeezing out the eyestalk from the base to the tip with the thumb and forefinger or using the fingers alone to break and squeeze the eye. The ablated females are stocked in maturation tanks at a density of 5 to 6 per square meter and a sex ratio of one male to one female.

¹³ Trash fish is a common industry term applied to by-catch that is processed and utilized as fresh feed for the shrimp.

2.4.4 Feed and fertilizers

The quantities of feed and fertilizers used by shrimp closely matches the intensity of culture. Extensive systems rely upon natural productivity, sometimes supplemented with small amounts of organic fertilizers. Semi-intensive, intensive and super-intensive culture methods require greater inputs of fertilizer and supplementary feed. As shrimp aquaculture has developed into a worldwide activity the use of formulated diets has become increasingly common which has increased even more so with the intensification of production methods. Support industries which produce feed are readily available in Thailand. This allows Thai shrimp to remain competitive in international markets because the main ingredients, such as fish meal and soybean for shrimp feed, which is the major shrimp production cost, are locally available.

Shrimp feed production for both local consumption and export is estimated to be over 400,000 MT/year, while production capacity is nearly double that. In 1992, shrimp feed production for local consumption was recorded as 320,000 MT (Table 2.10). In 1993, as the world's largest shrimp feed producer, C.P. Aquaculture manufactured 550,000 MT of shrimp and fish feeds (C.P. Aquaculture, 1994).¹⁴ Other major feed producing companies in Thailand include: S.T.C. Feedmill Co., Aquastar Co., Unicord Feed Co., Lee Feed Mill Co., Ta Tung Co., Krungthai Feed Mill Co., Lamthong Aquatech Co., and Silatip Sraburi Co.

Table 2.10 Production of industrial aquatic feeds in MT for domestic consumption in Thailand (1985 to 1992) (DOF, Bangkok, 1994a)

Year	Finfish and freshwater prawns	Marine shrimp	Total (MT)
1985	32,410	32,000	64,410
1986	56,620	36,000	88,620
1987	58,016	47,000	105,016
1988	60,000	100,000	160,000
1989	60,000	182,000	242,000
1990	80,000	240,000	320,000
1991	90,000	300,000	390,000
1992	90,000	320,000	410,000

¹⁴ C.P. Aquaculture is Charoen Prokphand and its different subsidiaries.

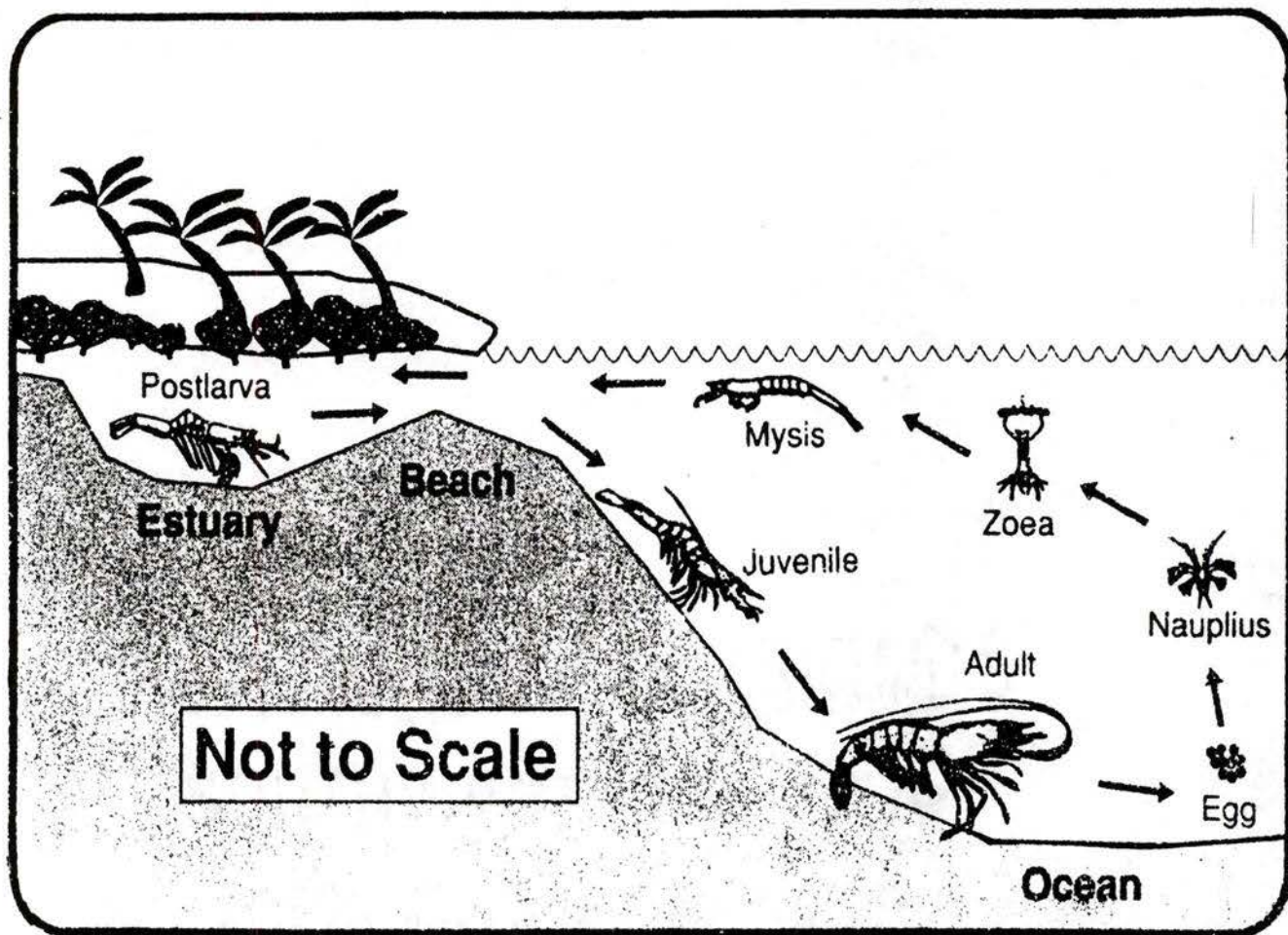


FIGURE 13. LIFE CYCLE OF PENAEID SHRIMP

2.5 Critical operating characteristics of Thai intensive shrimp farming operations

2.5.1 Feed inputs and waste production

The main adverse effect of the use of artificial feeds in shrimp farming is resultant increased nutrient and organic loading (Chamberlain, 1988; Jensen, 1991; Pruder, 1992; Boyd and Musig, 1992). Feed inputs introduce antibiotics into the grow-out ponds and, when combined with high feeding rates of intensive culture methods, cause problems within the culture ponds.

In Thailand, feeding rates of up to 450 kg/ha/d have been reported (Clifford, 1992). Feeds contribute 92 % of nitrogen (N), 51 % of phosphorus (P) and 5 % of solids entering shrimp ponds. Only 14 % of the pelleted feed inputs are incorporated into shrimp biomass, with 86 % being either metabolized by the shrimp or lost to the pond (Primavera, 1993). This condition reduces the pond's capacity to process organic material from feed and faeces, leading to accumulation in the pond sediments and the water column (Boyd, 1992). Excess nutrients and metabolites may become toxic (i.e. at > 0.1 mg/L as unionized ammonia) necessitating removal by water exchange, uptake by phytoplankton and sediment removal. None of these techniques are entirely effective at the high feeding rates of intensive operations.

2.5.2 Water quality management

Sustainable shrimp culture requires a healthy rearing environment. Susceptibility to disease is linked to stress and environmental quality (Lightner, 1984; Wyban et al., 1988; Lin, 1989, Fegan et al., 1991; Brock and LeaMaster, 1992; Chen, 1992; Nash et al., 1992). Environmental stressors such as low DO and high nutrient concentrations must be minimized.

Solutions involve management of the phytoplankton bloom (Krom and Neori, 1989; Chien, 1992), providing most of the pond oxygen requirements, and removal of toxic ammonia metabolites. Pond shading from the bloom must also be managed and

requires dilution with clean sea water as it develops. Insufficient water exchange would allow the bloom to become too dense and increase the risk of collapse (Fast and Lannan, 1992). The high feeding rates utilized in intensive ponds also leads to ammonia excretion rates that exceed what can be removed by phytoplankton or nitrified by bacteria. Therefore, water exchange is used to protect the crop by minimizing water pollution in the ponds.

Poor water quality management increases the stress on the shrimp crop and are generally attributed to inadequate water exchange from the lack of pumping capacity or poor farm location. The poor location and source water quality of some Thai shrimp farms has created problems in water quality management. Farms using canal water in southern Thailand have reported higher incidence of disease than farms using direct coastal sources (OEPP, 1994a,b). Thus, consideration of external water quality is essential to developing sustainable water management practices. This is an especially important for Upper Gulf shrimp farms.

2.5.3 Pond water aeration and circulation¹⁵

Intensive shrimp farms utilize high feeding rates that increase the organic content of accumulated sediment. Increased oxygen demand (BOD) and ammonia production in the culture ponds are the responses. The sediment represents approximately 75 to 84 % of the oxygen demand of an intensive shrimp pond (Fast et al., 1988; Hopkins et al., 1991), and shrimp pond sediment respiration rates have been estimated at 239 to 513 mg O₂ /m²/hr (Madenjian et al., 1987; Fast et al., 1988). In contrast, shrimp and the water column are minor consumers of oxygen, accounting for 2 to 4 % and 11 to 22 % respectively of the total demand of the pond (Fast et al., 1988). Oxygen requirements are met during the day by the phytoplankton bloom and mechanical aeration is instituted when photosynthetic oxygen production does not occur (i.e. evenings).

Aeration and circulation requirements increase with organic inputs (i.e. increased feed inputs for higher stocking densities). Aeration and water circulation prevent stratification and enhances oxygen delivery to the sediments and shrimp on the pond

¹⁵ Aerators are mechanical devices used to increase dissolved oxygen in the water. There are two types of aerators normally used in shrimp farms: Paddle wheels (oxygen enters water through splashing water into the air) and Propeller-aspirator-pumps (Air-O₂) (Bubbles of air are released into the water).

bottom. However, these interventions cause a gradual erosion of the pond bottom soils and increase sediment accumulation in the pond center. Thus one of the associated aspects of increasing stocking density is the requirement for increased water exchange and sediment removal. High levels of aeration are effective in maintaining water quality. The aeration requirements of different aquaculture systems were compared in Table 2.5.

2.5.4 Sediment management practices

Pond bottom sediment is the major sink for organic matter applied to the culture ponds. The erosion of the pond bottom soils resulting from aeration and circulation however, provides 91 % of the accumulated sediment. This high organic content of the pond forms the principal contribution to the overall organic content of the sediments and hence its oxygen demand and ammonia production (Boyd, 1992).

Accumulated sediment is either allowed to dry and removed, or washed out using high pressure hoses after each harvest (Boyd, 1992; Chanratchakool et al., 1994). Some sediment is usually left on the pond bottom and walls to prevent deepening of the ponds. With successive crops the pond sediment will be eroded and re-deposited with organic inputs from feed and faeces, accounting for a gradual increase in sediment organic content.

A period allocated for pond bottom drying is standard practice for pond renovation between shrimp farm cycles (Figure's 14 and 15). This allows for sediment sterilization and enhances organic matter breakdown by aerobic decomposition. If effective, the organic matter will be decomposed and will be returned to the soil from which it was eroded. This 'ideal' management practice is seldom allowed to occur completely as shrimp farmers often reduce the necessary dry out time between cycles. Combined with excessive feeding rates during the grow-out these practices then result in an increased organic content of the sediment with successive cycles, reducing the long-term biological viability of the culture pond.

The substantial amounts of accumulated sediment in the culture ponds after harvest must be removed during pond renovation and leads to disposal problems. Reported accumulation from Thai intensive shrimp farms ranged from 151 to 629 m³/ha (Funge-

Smith, 1993; Macintosh and Phillips, 1992; Tunvali et al., 1993).¹⁶ The high volume and salt content combined with the low nutrient concentration of these sediments suggest that their use as fertilizers is unfeasible. Potential uses have yet to be found and farmers generally distribute the sediment over vacant areas of the shrimp farm including the banks of the shrimp ponds.¹⁷ Some shrimp farms have incorporated central drains in the ponds to allow for continuous removal of sediment from grow-out ponds during the culture period. These design features are effective in improving adverse culture pond conditions but contribute high solid loadings to the receiving environment when discharged and would require treatment before discharge.¹⁸ Disturbingly, most shrimp farms employing these central drain systems do not include treatment systems and routinely discharge to receiving waters. The potential environmental impacts are severe, particularly in high density shrimp farming areas. Sediments contain 31 % of N and 84 % of P applied to the pond during the culture cycle (Boyd, 1992).

2.5.5 Chemical use

Globally, the number and quantity of chemical and biological products used in shrimp hatcheries and farm operations is increasing (Schnick, 1991). The intensive culture of animals in water requires chemicals to control disease, reduce handling trauma to organisms, disinfect water, improve water quality, enhance growth of cultured species and control aquatic vegetation, predacious insects, or other nuisance organisms. There have been several inventories of chemical usage in aquaculture (See Solbe, 1982; Schnick, 1991; Alderman et al., 1994) and a number of internationally observed standards have been reported (See Nauen, 1983). The classification of these products is based on their function of modes of action and are as follows: therapeutants, disinfectants, water and soil treatment compounds, algacides and pesticides, plankton growth inducers and feed additives. In addition to protecting the health of the cultured organisms, most shrimp farmers use pesticides to eradicate unwanted species in the shrimp ponds.

¹⁶ These sediments were characterized by low carbon (C) (0.7-1.0 %), N (0.1 to 0.15 %) and P (0.1 to 0.14 %) contents and typical C:N ratios of 3 to 9. A worldwide survey of pond soils (Boyd, 1992) indicated mean carbon contents of 1.4 % and C:N ratios of 5 to 9.

¹⁷ Strategies for the reclamation and management of salt-affected areas have been developed (ESCAP, 1990).

¹⁸ The use of central drains was observed on several occasions during the research in Thailand. The drain, located in the pond center where the majority of sediment accumulates, is connected to an engineered sluice at the pond edge. The farmer can then control the discharge by lifting the sluice manually. The effluent can best be likened to sewage sludge. It is black, tarry in nature with a very strong odor. The pond aeration units are positioned and operated in the culture ponds to promote the accumulation of sediment in the center of the ponds for this reason.

These substances include plant-based biodegradable pesticides such as tobacco dust (nicotine¹⁹), teaseed cake (saponin²⁰) and derris root extract (rotenone²¹), and many other organic pesticides. A detailed summary of common chemicals used in penaeid hatcheries and grow-out ponds is presented in Section 3.11. Prophylactic measures, such as vaccines, genetic selection and improvement of the environmental conditions, are most important in order to prevent disease outbreaks (Jacobsen and Berglind, 1988). However, when disease is a fact, medication is often utilized to prevent high mortality rates. The most convenient method of treatment with antibiotics and chemotherapeutics is via oral administration in feed additives. Calculations have shown that only 20 to 30 % of medicated food pellets is actually taken up by the organism whereas the rest, 70 to 80 %, reaches the environment (Samuelsen, 1989; 1991).

2.5.6 Waste production from shrimp processing facilities

The degradable organics in the waste stream from the growing numbers of processing operations for aquatic shrimp products are significant and show potential for the application of waste minimization practices and resource recovery systems. Table 2.11 presents the approximate waste produced during the processing of some aquatic products.

Table 2.11 Approximate waste produced during processing of some aquatic products (Subasinghe, 1994)

Raw material	Percent waste from processing
Oysters	75-80
Crab	70-75
Shrimp	50-55
Tuna	40-50
Salmon, Mackerel	30-35

¹⁹ The active ingredient in tobacco dust is nicotine. This pesticide is a potent non-selective type of poison. A dosage of 200 kg/ha is often utilized to kill undesirable predators especially snails and Cephalopods (Nuruzzaman, 1993).

²⁰ Saponin is extracted from teaseed cake which is a oil residue from processing of the *Camellia* sp. seed (Nuruzzaman, 1993). Teaseed cake contains 5.2-7.2 % saponin (Terazaki et al., 1980), a water soluble glucoside that causes hemolysis in organisms. The higher sensitivity to the glucoside of finfish compared to crustaceans has made it an effective pesticide in shrimp ponds (Minsalan et al. 1986). The effectiveness of saponin decreases with decreasing salinity.

²¹ Extracted from ground Derris sp. roots (i.e. plant origin). Also known as rotenone and is commercially available in powder form containing 4 to 5 % rotenone. Effective dosage for commercial rotenone is 2 g / m³ for eradicating the common predators such as finfishes and 8 g/ m³ for eel and crabs.



FIGURE 14. A TYPICAL POST-HARVEST INTENSIVE POND DURING DRY-OUT



FIGURE 15. INTENSIVE POND DURING DRY-OUT. ACCUMULATED SEDIMENT WILL EVENTUALLY BE REMOVED AND THE POND BOTTOM TREATED IN PREPARATION FOR RE-STOCKING

2.5.7 Annual operating cost of shrimp farming operations

The annual operating cost for different aquaculture systems in the Philippines was determined by Apud et al., 1983 (Table 2.12). For intensive systems the largest expenditure is feed. Power costs for pumping and aeration comprise 20 % of the total operating cost in intensive farms compared to 1.6 % for semi-intensive and nothing for extensive farms (Cited in Primavera, 1993 from Apud et al., 1983).

Table 2.12 Annual operating cost (% of total) for different aquaculture systems (Apud et al. 1983)

	Traditional	Extensive	Semi-intensive	Intensive
Fry	n.d.*	41.6	42.2	19.4
Feed	n.d.	11.5	31.0	51.1
Labor	n.d.	5.8	1.4	3.1
Power	n.d.	0	1.6	19.5
Others**	n.d.	41.1	23.8	6.9

* n.d.=Not determined

**Includes lime, fertilizer, teaseed, other supplies and repairs.

2.6 Coastal shrimp aquaculture in Thailand - Social and economic considerations

A review of social and economic considerations of current production is best accomplished through a detailed exploration of the historical development. Only then can production figures and their trends globally, in Thailand and in the Upper Gulf be fully appreciated.

2.6.1 Historical development of the Thai shrimp aquaculture industry

Shrimp farming consisting of the production of marine shrimp in impoundment's can trace its origins to Southeast Asia. Early farmers raised incidental crops of wild shrimp in tidal fish ponds. Modern shrimp farming originated in Japan in the 1930's where Dr. Motosaku Fujinaga, the pioneer of larval culture, began hatchery work with the kuruma shrimp (*Penaeus japonicus*) (Shigueno, 1975). In the 1970's and early 1980's, when fishermen and hatcheries began supplying large quantities of juvenile shrimp to farmers, production of farm-raised shrimp exploded. The present section traces the evolution of

present day shrimp farming practices in Thailand highlighting the areas covered and distribution of the farming activity, the intensification of methods and subsequent abandonment of some farming operations. The first Thai intensive shrimp culture operations were concentrated along the Upper Gulf of Thailand provinces making this region the 'cradle' of Thai shrimp culture.

Shrimp farming methods have undergone tremendous change since the time of the early subsistence culture methods. This transformation includes transition from extensive mixed species in trapping-growing ponds to the present day monoculture, primarily of the black tiger prawn. The evolution of shrimp farming in Thailand can be divided into four significant periods: (1) the foundation phase of the pre-1980's; (2) the expansion phase from 1978 to 1987; (3) the intensification phase from 1987 to 1990; and (4) the post-intensification phase beyond the 1990's (Table 2.13). These phases outlining the evolution of shrimp farming practices in Thailand can be applied to most countries that have adopted the intensive system after adjustment of the years for in which the phases occurred.

Table 2.13 Phases of evolution of shrimp farming practices in Thailand

Foundation phase (pre-1980's)
<ul style="list-style-type: none"> • Creation of the first shrimp farms during the pre-1960's period through the flooding of coastal low land areas. • This practice then changed to open extensive flooding for the early operations during the 1960's.
Expansion phase (1978 to 1987)
<ul style="list-style-type: none"> • Rapid development of methods, supported by government, from extensive and semi-intensive to intensive using the Taiwanese model.
Rapid intensification phase (1987 to 1990)
<ul style="list-style-type: none"> • Open or flow-through intensive and semi-intensive systems are the current industry standard. Very little or no recycling through treatment methods or by the adoption of integrated systems. • Farms are quickly established at high production levels, suffer problems, and are abandoned
Post-intensification phase (beyond the 1990's)
<ul style="list-style-type: none"> • Semi-closed intensive farming with few commercial farms • Closed intensive and open semi-intensive farming utilizing intact mangrove areas. Few applications to date.

2.6.1.1 The foundation phase (pre 1980's)

The gradual foundation or entry phase of shrimp culture in Thailand was introduced by the development of an early extensive culture system for marine shrimp. This extensive system relied on natural seed and feed to rear mixed species of crustacean and fish in large tidal 'trapping-growing' ponds (Lin, 1995). The most commonly reared shrimp species were banana shrimp (*Metapenaeus merguensis*), school shrimps (*Metapenaeus monoceros*, *M. ensis*), Indian white shrimp (*Penaeus indicus*) and some black tiger shrimp. There are few records documenting when the cultivation of shrimp in ponds commenced in Thailand. By interviewing local farmers, Tiensongrusmee (1970) found that shrimp farming existed prior to 1930. Other sources indicate that shrimp farming has been practiced in Thailand for the last 55 years (Tookwinas, 1993). Initially, farmers reclaimed estuarine areas for rice cultivation. These areas were typically low lying zones with water supplied by canals. The water contained in these areas was fresh during the rainy season and brackish in subsequent periods. Therefore, the rice fields could only be operated for a few months during the rainy season. After the rice paddy was harvested, brackish water was allowed to flow freely in and out of the field allowing shrimp and other estuarine dependent species to occupy the paddy. These extraneous fish and shrimp species became extra income for the rice farmers. The profits available from selling the paddy fish and shrimp provided incentives for the farmers to convert their paddies into shrimp ponds. Thus, it is clear that early shrimp farming developed from a small group of rice farmers who lived in the estuarine areas. Shrimp farming also became popular to salt farmers in the same area. Up until about 1950, the salt farming industry was depressed in the Upper Gulf provinces of Samut Prakan, Samut Sakhon and Samut Songkhram. As the profitability of salt production declined suitable salt ponds were used year round to produce shrimp. By the end of the 1960's more than 50 % of the salt farms were converted to aquaculture (Csavas, 1994a). Initially, the farmers used simple methods of excavation and diking around the desired areas to retain sea water. Techniques were gradually refined and improved by trial and error.

2.6.1.2 The expansion phase (1978 to 1987)

In the 1970's the combination of several factors lead the way for a rapid change in shrimp culture methods in Thailand. This change manifested itself with the proliferation of shrimp farms in 1972 when the DOF promoted the new intensive culture technologies (Katesombun, 1992). This expansion was partially facilitated by the development of

hatchery technology in the late 1960s which allowed for the production of large numbers of larvae for stocking ponds (Liao, 1990). These technological breakthroughs occurred primarily in the seed and feed supply systems of shrimp farming. As early as 1973 at a DOF station Thai technicians trained in Japan were successful in mastering the hatchery and nursing of the *Black tiger shrimp* and the *Penaeus merguensis* species. While Thailand proceeded with the development of more intensive methods in the middle 1970's countries which maintained traditional tidal trapping-growing ponds were primarily India and Taiwan.

2.6.1.3 The shrimp culture boom - Intensification, pollution and abandonment (1987 to 1990)

The intensification of shrimp farming in Thailand from 1987 to 1990 is a recent phenomena and was based on the Taiwanese model.²² Previous advances in the supply of feed and seed created opportunities for rapid development in Thailand. In the early 1980's shrimp farmers in Thailand, with government support, started to increase the intensity of traditional shrimp culture systems through the use of simple and affordable 'push pumps'. Average yields began to considerably exceed those of other Southeast Asian countries using the same extensive trapping-growing techniques (Csavas 1994a). Shrimp production levels of up to 20 MT/ha/yr being achieved (Csavas, 1992). The government further supported the intensification of methods following Thailand's 1981 ratification of the 200 mile exclusive economic zone in the Gulf of Thailand. This decision limited Thailand's catch of wild shrimp to the Thai-operated parts of the Gulf and the Andaman sea on the west coast and put special emphasis on shrimp culture development in all coastal areas. The government saw this as an opportunity to promote shrimp farming as an alternative livelihood and to increase protein production as the capture fisheries in the Gulf of Thailand declined. However, it would not be until 1989 that the widespread farming of marine shrimp, primarily black tiger prawns (*P. monodon*) would begin. During this period between the early 1980's and 1989 the main

²² The Taiwanese ponds are earthen or cement, with a depth of 1.8 to 3 meters and an acreage of between 0.16 to 2 hectares. Densities are in the order of 5,000 to 30,000 shrimps per hectare. A rough estimate of the daily industrial feed requirement is 10% of the shrimp biomass during the first months, which drops to 4% during the last month. There are 2.5 to 3.5 crop cycles of three or four months per year. Based on this model the general characteristics of intensification are as follows: Intensification included stocking increasing numbers of hatchery-reared shrimp (up to 100 animals m⁻²), supplying large quantities of pelleted feeds (up to 450 kg ha⁻¹ d⁻¹), decreasing pond area (to 0.3 to 1.0 ha), increasing pond depth (to 1.2 to 1.6 m), high water exchange rates (up to 30 % pond volume d⁻¹) and mechanical methods of aeration and water circulation (up to 27 kW (20 hp) ha⁻¹).

target of output changed from domestic consumption to export. The decisive change that occurred in 1989 was primarily triggered by the demise of the Taiwanese shrimp farming industry.

During the period from 1987 to 1990 in Thailand, enormous intensification and investment in shrimp culture increased output five-fold in three years from 23,566 MT to 118,227 MT (Appendix D), whereas the number of production units (or shrimp farms) only increased two and a half times from 5,899 to 15,072. The cultured area had only increased from 52,149 ha in 1987 to 64,606 ha in 1990 (Appendix D). The four-fold increase in the average yield (i.e. MT per hectare) increased from .45 MT/ha to almost 1.8 MT/ha in 1990, illustrates this increase in productivity (Appendix D). This intensification was not evenly distributed and some was helped along by the semi-intensive shrimp farmers but most of the increase resulted from the adoption of intensive culture systems, where the one tonne yield/ha of 1987 was multiplied four times. The success of the intensive system is illustrated by its preponderant share in the number of production units, cultured acreage, and production figures.

The extensive system was still predominant in 1987, when it was practiced by 3,554 holdings, covering 31,296 ha, but in 1990, there were only 2,824 operators on 20,856 ha. In the semi-intensive system, the number of operators and acreage doubled between 1987 and 1988, then underwent a stagnation and stabilized at 20,656 ha in 1990 with 3,478 units. It was the intensive system which grew most spectacularly, where the number of units increased six-fold in three years, giving 9,997 units in 1990, and where the total acreage almost tripled to reach 24,335 ha (DOF, 1994b). The degree of intensification which occurred in the provinces of the Upper Gulf of Thailand will be discussed in Chapter 6. The measure of intensification will be useful in the sustainability assessment portion of this thesis.

The rapid development of intensive culture operations was accompanied by pollution which has impacted existing operations to the extent that operators were forced to abandon their ponds. The initial rapid expansion of intensive shrimp culture saw the wholesale conversion of salt and extensive shrimp ponds to intensive ponds as the high producing *Black tiger shrimp* culture practices were adopted, and the conversion of mangrove, rice paddy and other coastal lands into new highly productive shrimp farms (Ferdhouse, 1990; Liao, 1990; New, 1991; Menasveta, 1992; Anon., 1993b; Stanley, 1993a,b). The current disposition of these lands presents a different picture for the

future of shrimp farming. Pollution has resulted in abandonment of some culture areas. For example, in 1994, it was determined that there are currently 3,555 ha of 'abandoned' or 'idle' farms in Samut Sakhon alone (OEPP, 1994b).

2.6.1.4 Post-intensification phase (beyond 1990)

The Thai shrimp industry is now in the post-intensification phase of development. The global shrimp culture industry has now matured with the world production in 1994 reaching 713,500 MT (Figure 16). The current position of the industry presents two options: (1) maintaining the productivity of the industry by improving performance or (2) yielding to the economic, ecological and social pressures and accepting contraction. The expansion likely will continue, *albeit*, at a decelerating pace (Csavas, 1994b). It is clear from statistics that in Asia, rapid aquaculture development and substantial economic losses are experienced simultaneously (Anon., 1994b).

The post-intensification phase for Thailand is a critical period. Most shrimp farms continue to operate business as usual in the face of uncertain outcome while few others are adapting and changing practices so as to be better prepared for the future. The responsibility and accountability for restoring areas left damaged by shrimp farming remains unresolved. Although the industry has changed some of its operating practices to lessen impacts these changes only apply to new and existing operations and are far from attempting the reclamation of older damaged sites.

The next section provides current economic statistics globally, for Thailand as a whole and for the Upper Gulf region.

2.6.2 Current world and Southeast Asia shrimp aquaculture production

Shrimp farming is now practiced in over fifty countries worldwide and is consolidated primarily in two major areas of the world, Asia and Latin America (Weidner, 1988; Weidner and Rosenberry, 1992; Wildman et al., 1992; and Rosenberry, 1993). The industry continues to expand and marine shrimp ponds are constructed in many developing tropical countries in order to sell shrimp on the international market to meet the large demand from developed countries. During the years from 1991 to 1994 Thailand has maintained its position as the world's leading producer of farmed shrimp (Figure 16). The noticeable discrepancies between 'total production' figures and 'import' of aquaculture products worldwide are accounted for in the quantity of shrimp products

consumers in producing countries. Most of the major shrimp producing countries have all previously been the world's leading producer of shrimp in the years prior to 1991. For the moment, Thailand enjoys being the 'top' shrimp producing country globally.

2.6.3 Current production in Thailand as a whole

Cultured shrimp production in Thailand is supplied by over 2,000 hatcheries (Anon., 1995b). Of this total production more than 90 % is accounted for from 40,000 ha of intensive *Penaeus monodon* Fabricius culture ponds (Csavas, 1992; FAO, 1992; Menasveta, 1992; Anon., 1993a,b). Shrimp production from captured marine shrimp was previously the largest supplier. In 1972, for example, 67,878 MT of shrimp were produced, with only 1.5 % from culture operations. However, in 1989, total production from culture operations exceeded wild shrimp production for the first time in Thailand. Thai landings of captured shrimp had reached a plateau of approximately 85,000 MT. Cultured shrimp had kept the supply expanding from just 10,091 MT in 1982 to over 162,000 in 1991. In 1991, 242,070 MT of shrimp were produced 67 % from culture operations (Figure 17).

2.6.3.1 Export earnings from the Thai shrimp aquaculture industry

In Thailand, the main merchandise export of shrimp in 1992 was valued at \$US 2.04 billion and ranked second behind only the export of textiles which was valued at \$US 6.21 billion. However, Thailand's textile industry exports still represents more than three times the value of prawn exports. The next highest ranked exports in 1992 were precious stones/jewelry at \$US 2.03 billion and rice at \$US 1.76 billion. The export value of prawns represented 3.8 % of Thailand's main merchandise exports in 1992 gradually increasing from 1.9 % in 1987 (Anon., 1993c).

Figure 16. World shrimp production (MT) from aquaculture from 1991 to 1994
(Anon., 1994a and Anon., 1995)

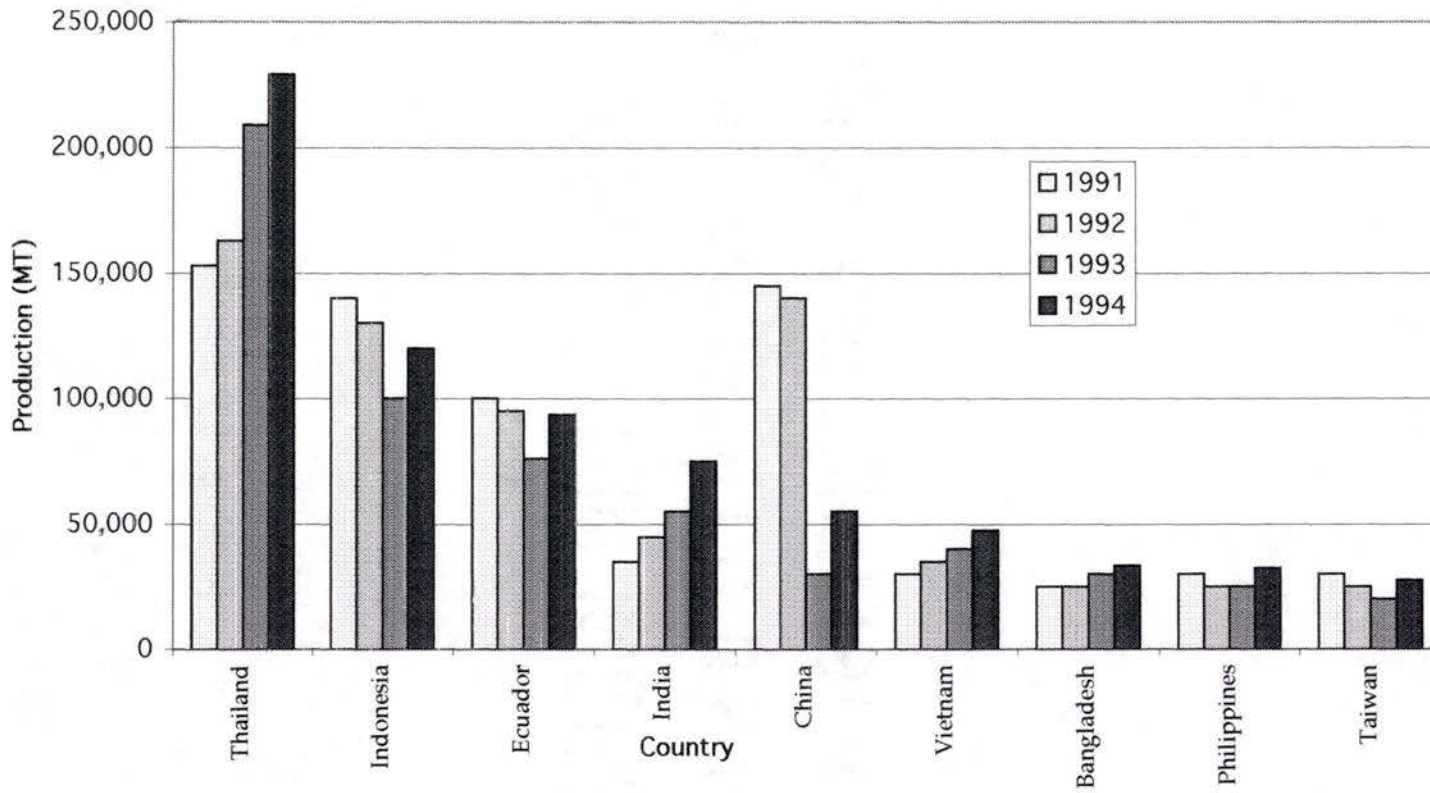
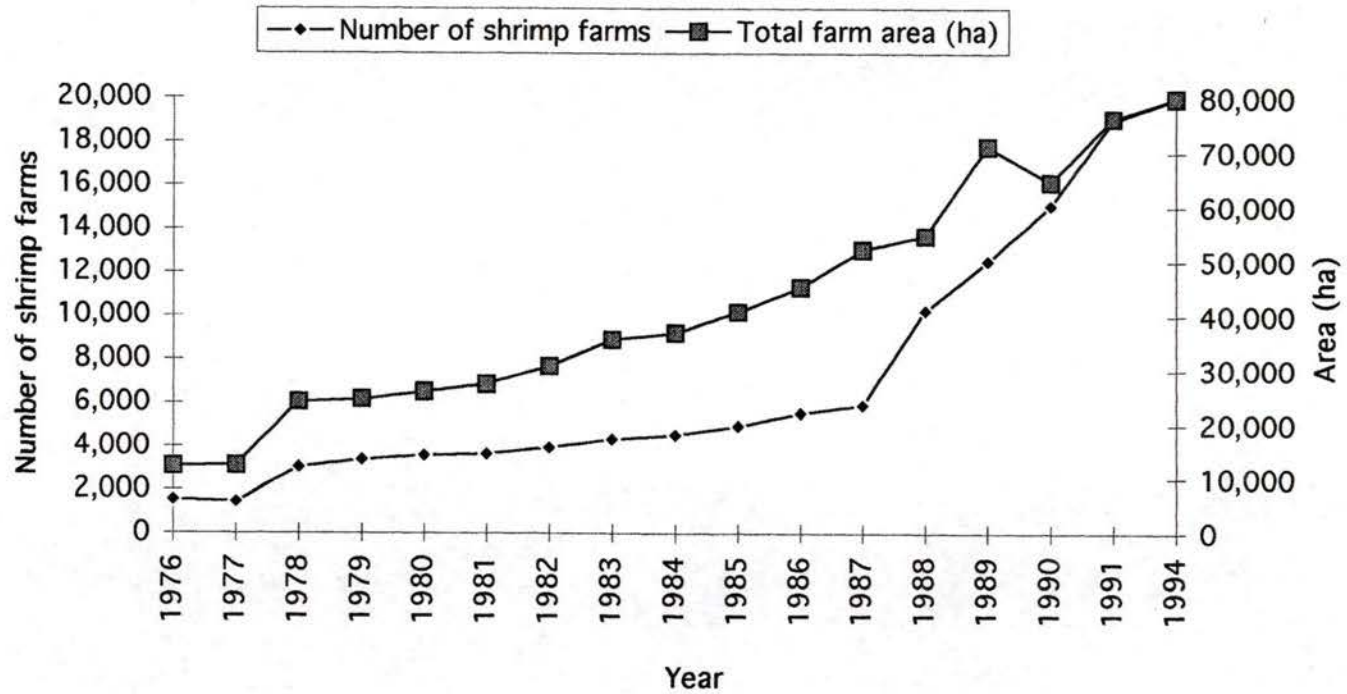


Figure12. Number and area of shrimp farms in Thailand from 1976 to 1990(NACA, 1994) and for 1994 (Anon., 1995b)



2.6.3.2 Other coastal and freshwater aquaculture species

The production of other coastal and freshwater aquaculture species fluctuates due to shifts in local demands which has included the transfer to intensive shrimp farming methods. To demonstrate this phenomenon the production of several key regional species, during the period prior to and after the events of the Upper Gulf, are presented (Table 2.14). Several species cultured in the Upper Gulf region represent important income and food sources for the coastal dwellers. Some of these species have the potential for application as part of integrated shrimp culture systems or utilization in the abandoned ponds as replacement crops to shrimp.

Table 2.14 Other coastal and freshwater aquaculture products of Thailand in 1991 (FAO estimate from available sources of information, 1993)

Coastal Aquaculture	Production (MT)		
	1987	1989	1991
Green mussel (<i>Mytilus smaragdinus</i>)	46,783	58,669	65,000
Horse mussel (<i>Modiolus sp.</i>)	272	46	1,000
Blood Cockle (<i>Anadara granosa</i>)	9,609	12,822	12,500
Cupped Oysters (<i>Crassostrea sp.</i>)	1,483	1,399	1,500
Seabass (<i>Lates calcarifer</i>)	1,183	1,290	1,100
Grouper (<i>Epinephelus sp.</i>)	343	447	430
Mud crab (<i>Scylla serrata</i>)	113	20	30
Freshwater Aquaculture			
Nile tilapia (<i>Oreochromis niloticus</i>)	16,980	21,115	25,000

2.6.4 Aquaculture in Upper Gulf of Thailand

The Upper Gulf provinces include: Chonburi, Chachoengsao, Samut Prakan, Bangkok, Samut Sakhon, Samut Songkhram, Ratchaburi, and Phetchaburi. A detailed province-by-province analysis of production reveals that the overall growth has been disproportionate despite the overall production increases from Thai shrimp culture. Shrimp production from the Upper Gulf region remains significantly reduced when compared to former production figures. Table's 2.15, 2.16 and 2.17 below present the changes in shrimp farm area, production and number of farms respectively from 1987 to 1992. The shortfall from this region was accounted for by the development and increase in production output from the 'new' regions in eastern and southern Thailand. The migration and expansion of the industry from the Upper Gulf region is discussed in a later section.

2.6.4.1 Production

Table 2.15 presents the shrimp production for the provinces of the Upper Gulf of Thailand from 1987 to 1992.

Table 2.15 Upper Gulf of Thailand total shrimp production (MT) from 1987 to 1992 (DOF, 1994b)

Province	1987	1988	1989	1990	1991	1992
Chonburi	148	153	293	457	1,356	945
Chachoengsao	778	2,834	2,887	7,978	4,880	9,844
Samut Prakan	3,934	3,094	6,332	4,243	2,964	1,182
Bangkok	1,395	1,577	1,102	1,312	827	652
Samut Sakhon	5,403	14,407	13,819	9,989	2,980	2,162
Samut Songkhram	3,548	12,333	11,046	7,957	2,319	969
Ratchaburi	0	0	0	0	0	0
Petchaburi	415	1,353	5,574	4,399	3,407	2,853
Total	15,621	35,751	41,053	36,335	18,733	18,607

2.6.4.2 Shrimp culture area

Table 2.16 presents the shrimp culture area for the provinces of the Upper Gulf of Thailand from 1987 to 1992.

Table 2.16 Upper Gulf of Thailand shrimp culture area (ha) from 1987 to 1992 (DOF, 1994b)

Province	1987	1988	1989	1990	1991	1992
Chonburi	590	667	660	624	678	498
Chachoengsao	1,786	1,728	1,609	3,283	3,123	2,716
Samut Prakan	7,255	7,591	7,650	6,080	6,316	6,052
Bangkok	4,372	4,178	4,364	3,603	3,234	3,117
Samut Sakhon	8,077	9,722	12,134	8,013	8,189	7,395
Samut Songkhram	7,332	6,021	7,112	3,857	2,654	2,613
Ratchaburi	0	0	0	0	0	0
Phetchaburi	2,711	1,893	4,192	2,912	3,410	2,443
Total	32,123	31,800	37,721	28,372	27,604	24,834

2.6.4.3 Number of aquaculture operations

Table 2.17 presents the total number of aquaculture operations recorded for the Upper Gulf of Thailand during the period 1987 to 1992.

Table 2.17 The total number of shrimp farms in the Upper Gulf of Thailand from 1987 to 1992 (DOF, 1994b)

Province	1987	1988	1989	1990	1991	1992
Chonburi	80	121	120	122	137	5,364
Chachoengsao	293	306	313	1,078	788	1,724
Samut Prakan	1,206	1,535	1,535	1,211	1,243	1,121
Bangkok	811	975	983	631	571	544
Samut Sakhon	1,173	2,101	2,295	1,877	1,210	1,150
Samut Songkhram	890	1,271	1,244	577	472	386
Ratchaburi	3	3	0	0	0	0
Petchaburi	280	622	620	478	641	323
Total	4,736	6,934	7,110	5,974	5,062	5,461

2.7 Impacts of coastal shrimp aquaculture on the surrounding environment

The environmental impacts of shrimp farming, both long-range and immediate, are widespread and experienced by both shrimp farmers and other coastal zone land users. Coastal aquaculture is often 'self-polluting' and negatively impacted by its own practices. The method of culture determines the overall environmental impact (Beveridge, 1984; Braaten et al., 1988) mainly through the degree of intervention into, or manipulation of, the natural ecosystem. Accordingly, the environmental impacts from aquaculture operations relate to the scale of the operation. With increasing intensification, stocking densities have increased and more environmental problems have emerged (Chiang and Liao, 1985). As the intensive shrimp culture system has become the fastest expanding aquaculture in the tropics, its impacts on the coastal environment has been a cause of great concern (Phillips et al. 1993). Therefore, focus will remain on intensive shrimp culture operations that utilize formulated feeds, water pumps and aeration with production. These impacts commence during farm site selection and construction and continue during the entire life cycle of the farm. This adds complexity to understanding and assessment of impacts considering that the activity of shrimp farming requires the management of systems under relatively uncertain conditions. The overall range of impacts are introduced in this section.

2.7.1 Strategies and guidelines to assess environmental impacts

Numerous strategies and guidelines have been developed to address the environmental impacts of coastal aquaculture worldwide. For example, recent reports deal with the following issues: management and assessment of the environmental impacts of coastal aquaculture developments (Barg, 1992); sustainable development of coastal environments (UNEP, 1990; Sorensen and West, 1992; Swaminathan and Ramesh, 1993; Srirama Murthi, 1993; Gaur, 1993; Sloan and Sugandhy, 1994; Towfighi, 1994); an ecological economics approach to coastal zone management (Ruitenbeek and Cartier, 1992); guidelines for developing countries (Ahmad and Sammy, 1987) and sectoral guidelines for environmental assessment (World Bank, 1991).

Studies by the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) have identified the key areas of environmental concern for coastal aquaculture operations: human health, site selection, nutrients and organic enrichment, chemicals and exotics. Some of the evolving techniques and procedures include the consideration of environmental and human health risk assessment techniques to be applied prior to aquaculture operation commencement (Kingsley, 1986; Wile, 1993). Several countries have farm development guidelines and review procedures in place specifically for aquaculture projects (e.g. Indonesia). Although the overall outcome of these exercises may be beneficial to the environment, the motivation for these initiatives for the moment is primarily to protect the potential investor's capital (i.e. financial risk) or meet bank loan requirements (e.g. World Bank, Asian Development Bank). The future of environmental impact assessment worldwide should see the implementation of Agenda 21, Chapter 17. This chapter reports on the type of activities which should be undertaken in order to reduce undesirable impacts on the environment and conflicts among users and between groups or individuals (UNCED, 1992).

2.7.2 Previous research on the environmental impacts

Numerous reviews have examined and presented the specific environmental impacts of coastal shrimp aquaculture (Bailey, 1988; ICES, 1990; Pillay, 1989; Pullin, 1989; Braaten and Hektoen, 1991; GESAMP, 1991; Pullin, 1993; Phillips et al. 1993; Primavera, 1994;

Rosenthal, 1994; Landesman, 1994; and Baird and Quarto, 1994).²³ Similarly, the ecological and physico-chemical effects of coastal aquaculture have been the subject of numerous studies (Kaspar et al., 1985; Brown et al., 1987; Rosenthal et al., 1988; Jacobsen and Berglind, 1988; Lumb, 1989; Ritz et al., 1989; Growen et al., 1990; Mäkinen, 1991; Barg, 1992, Chua, 1992, Gowen, 1992). The major impact is the direct removal and destruction of coastal habitats (Chua et al., 1989b). Marine and freshwater resources have been compromised (Primavera, 1992; Masae and Rakkheaw, 1992); saline intrusion has effected farm land (Liao, 1990; Anon, 1992a; Primavera, 1992; Anon, 1993d; Csavas, 1993a; Phillips et al., 1993; OEPP, 1994a,b); removal of freshwater from underground aquifers has resulted in subsidence of coastal land (Chiang and Lee, 1986; SEAFDEC, 1989; Primavera, 1989). This is a highly active area of research and publication; all indications are that it will remain so.

The range of environmental impacts associated with intensive coastal aquaculture include: **ecological** (terrestrial, aquatic, land); **physico-chemical** (land, surface water, ground water and atmosphere); and **human interactions** (health, socioeconomic, aesthetics and cultural) from a wide range of sources (construction, site development, operation, processing, site abandonment and decommissioning and closure). Table 2.18 presents the major environmental impacts to coastal zones resulting from intensive coastal aquaculture.

²³ Some of the socioeconomic impacts: Land cost has increased dramatically (Brown, 1989; OEPP, 1994a,b) and coastal communities have been marginalized (Bailey, 1988; Chong, 1990; Csavas 1990; Primavera, 1992; Masae and Rakkheaw, 1992).

Table 2.18 The major environmental impacts in coastal zones resulting from intensive coastal aquaculture operations

-
- Wetland habitat destruction: construction of the shrimp farms (primarily the encroachment and destruction of mangroves).
 - Water quality degradation and nutrient and organic enrichment: of coastal waters (i.e. eutrophication²⁴ - increased primary productivity and hypernutrification of estuarine ecosystems from shrimp pond effluent).
 - "Biological pollution" of native shrimp stocks through escapement of aquaculture stocks²⁵
 - Impacts of farm chemicals on estuarine ecosystems and consumers
 - Pollution from shrimp processing wastes²⁶
 - Land alienation and conflicts with other users
 - Land subsidence
 - Adverse effects to wildlife and fisheries
 - Salinization of ground soils and aquifers
 - Loss of profitability of traditional livelihoods
-

The environmental impacts of aquaculture remain poorly understood. In most cases their full extent have yet to be quantified with environmental impact or ecological risk assessment techniques. The lack of precise information demonstrating the interactions between aquaculture and the environment is the most notable deficiency. For example, the knowledge of the impacts of chemicals used in aquaculture is limited and is currently being reviewed by the International Council for the Exploration of the Sea (ICES). Also, the effluent from shrimp farms which contains a mix of introduced chemicals and organics cause severe sedimentation and obstruction of water flows in areas of restricted water supply and heightens the possibility of hypernutrification or eutrophication of

²⁴ Eutrophication: Process of nutrient enrichment (usually by nitrates and phosphates) in aquatic systems, such that the productivity of the system ceases to be limited by the availability of nutrients. Occurs naturally over geological time but may be accelerated by human activities and is sometimes referred to as 'cultural eutrophication'.

²⁵ An alteration in the gene pool of naturally occurring shrimp may occur with inter-breeding of escaped cultured stock and wild populations. This escape of shrimp from grow out ponds is not infrequent, sometimes occurring on a large scale resulting from seasonal flooding. For example, a single flooding event in 1988 led to the release of 10 million *P. monodon* into the waters off Southern Thailand. The shrimp species utilized in most of Thailand and for the province of Samut Sakhon are found naturally in the local waters and so there is minimal risk to the gene pool through the escapement of aquaculture stocks.

²⁶ There are indirect impacts of aquaculture projects that result from the processing and transport of shrimp. The effluent from fish processing operations is high in organic matter (offal and blood), oil and grease, bacteria, nitrogen and suspended solids. Untreated effluent is discharged to estuarine and coastal ecosystems. Impacts can include oxygen depletion, fish kills and increased turbidity. Settling of suspended solids affects corals, sea grasses and other bottom dwellers. Information on these impacts is scarce. They will inevitably increase as production rises.

coastal waters and estuarine areas. The potential for severe consequences is a concern. Other ecological concerns include the changes resulting from the introduction of exotics, human health effects. Aesthetic impacts of shrimp farms and the impacts to wildlife are other areas which have received little or no consideration to date but have potentially very serious implications.

This lack of information on environmental impacts reduces the sustainability of shrimp farming. For this reason, specific environmental impacts of concern are discussed in conjunction with the identification of critical indicators of sustainability in Chapter 6.

2.8 Key legislation and government agencies in Thailand

2.8.1 Key legislation

The new *National Environmental Quality Act* (1992) (from here on in NEQA) - introduced sweeping changes to Thailand's environmental management system. A key feature of the Act is that it, in theory, decentralizes ultimate decision making over pollution related matters, putting it firmly in the hands of officials at the local (i.e. provincial) level. Potentially siting of aquaculture farms could be critically influenced. Provincial governors have been empowered, again in theory, to set more stringent environmental criteria than national regulations (which provide only a minimum standard). In practice, decentralization has proceeded slowly, and no real initiative has been taken at the local level. Another important feature of the law is that it establishes the "polluter-pays" principle. Under the law, polluters would not only be fined but would also be liable to pay full compensation.

Other legislation that may have an effect on the operation of shrimp farms (or any associated industries) was also introduced in 1992. The *Hazardous Substances Act* (1992) is a legal springboard towards a comprehensive system for management of hazardous substances and wastes. The act is implemented by the ministries of Industry, Agriculture and Public Health. The *Factories Act* (1992) empowers the Ministry of Industry to set standards governing pollution control and gives Ministry of Industrial Works (MOI) the power to inspect all factories. The *Public Health Act* (1992) provides a management framework relating to urban solid wastes and public nuisance complaints.

2.8.2 Surface, sea, aquaculture and other effluent standards

For the full information of the reader a number of standards and guidelines established in Thailand or recommended by expert study have been assembled in Appendix A. Tables for the following are provided: standards for sea water quality, surface water classification, water quality standards for coastal aquaculture, and the river water classification for the Thachin and Chao Phraya rivers. In addition, a number of comparisons of toxicity values are presented that will be useful for the discussion of the field data in Chapter 5. In particular, the suitable levels for intensive shrimp culture operations for selected environmental parameters is introduced (See Appendix A).

Water bodies are designated water quality categories according to the intended usage. Some rivers - including the Chao Phraya and Thachin rivers - have already been classified, but the vast majority of surface and coastal waters remain to be classified (Appendix A). Coastal water quality is classified as one of the seven types with a set of acceptable standard values (Table 2.19). All of the above legislation and standards should become increasingly important in the commissioning, operation, and de-commissioning of shrimp farms and associated industries. The current position of the government in terms of having the political will to effectively enforce these laws is discussed in Section 6.

Table 2.19 Classification of coastal water source types in Thailand (ONEB, 1991)

Type	Utilization
1	For natural observation, water quality is natural and can be used for: 1. Study research and/or scientific demonstration that make no environmental changes through observation or examination. 2. Activities that exploit the natural beauty and scenery. 3. Activities that concern with the management and conservation which make no environmental changes.
2	For coral conservation
3	For conservation of other natural resources (i.e. mangrove, living ground of beast, breeding ground, nursery ground, and food source of marine aquatic organisms).
4	For coastal aquaculture such as mollusk culture, shrimp culture, fish cage culture etc.
5	For swimming.
6	For other water sports such as sailing.
7	For industrial zones (i.e. to conduct industrial activities such as mining and/or used to receive industrial wastewater - water quality not lower than the assigned standard).

2.8.3 Government environmental agencies

Under NEQA, the Ministry of Science, Technology and Environment (MOSTE) enjoys overriding powers to enforce environmental regulations. Thus, MOSTE can act if the Department of Industrial Works (DIW) does not enforce environmental regulations stringently enough. So far, MOSTE has adopted a cautious approach to lax enforcement of environmental laws and regulations. Much of MOSTE's environmental responsibilities falls on the shoulders of the Pollution Control Department (PCD). The organization was only set up in 1992 (as a result of NEQA). The formulation of environmental quality and emission standards has not been completed by the PCD. The role of the above agencies in terms of Thai coastal shrimp aquaculture operations will be discussed below.

2.9 Policies, rules, and regulations related to coastal shrimp aquaculture

Thailand is in the formative stage of the development of comprehensive legislation and policy to regulate aquaculture. Both the national level policies that are being used to guide coastal aquaculture development and the central governments response in the way of policy support this assessment. Specific legislation has been enacted by the DOF in response to the environmental problems resulting from coastal aquaculture development (Table 23). The DOF is the key agency in Thailand for the planning, implementing, administering control (enforcement) of coastal zone activities. Aquaculture practices will be subject to more stringent environmental control in the future including. In particular, there should be an increase in the financial responsibility of developers to account for the environmental impact of new developments.

2.9.1 National level policies

As part of economic development aquaculture in Thailand is guided by the National Economic and Social Development Plans. The commitment to coastal aquaculture development is demonstrated by the central government's guiding policies written into the National Economic and Social Development Plan for 1992 to 1996 (Table 2.20). The interpretation of these guiding policies will be discussed in Chapter 6.

Table 2.20 The guiding policies for coastal aquaculture as found in Thailand's Seventh National Economic and Social Development Plan (1992 to 1996) (i.e. known as "the Five-Year Plan")

-
1. Undertake the extensive propagation of brackish water cultivable species.
 2. Increase the production from coastal aquaculture by developing techniques for intensive culture of commercial species.
 3. Support the use of remote sensing along with ground survey for coastal zone aquaculture development.
 4. Emphasize effective techniques for coastal conservation of living things.

2.9.2 Central government policies directing the Department of Fisheries

The government has initiated specific responses to the seventh National Economic and Social Development Plan (1992-1996) that would help to achieve a sustainable aquaculture industry. The interpretation of these points with respect to the sustainability of the industry in Thailand will be discussed in Chapter 6.

1. Regulations in the government sector which have delayed the development of coastal aquaculture should be rapidly rectified.
2. Local and provincial policies regarding the management of coastal aquaculture should be immediately planned and implemented. A data base on coastal aquaculture should be established.
3. The quality of natural resources affected by environmental pollution should be restored. Those which affect capture and culture fisheries should receive high priority.
4. Coastal aquaculture should be developed to achieve better results and pay due concern for the utilization of coastal land and in the development of coastal areas.
5. Small-scale shrimp farmers should be encouraged to form groups that utilize modern shrimp farming techniques. A knowledge of conservation and maximum profitable utilization of coastal resources should be transferred to shrimp farmers and to those people with interests in the shrimp industry or the areas which it operates.

The above central government policies affect progress towards achieving sustainability of the current industry. Themes can be best interpreted as an indication to proceed without constraint. They do not represent a rapid timetable for action.

Implementation of central government policies has been delegated from the central government authorities to the DOF, Ministry of Agriculture and Cooperatives. To carry out this mandate the DOF formulated a twelve point plan (Table 2.21). To implement this plan the DOF (1994) developed guidelines summarizing the current Thai government policies regarding shrimp production (Table's 2.22 and 2.23).²⁷ The stated goal of such directives was "to protect the existing aquaculture industry and reduce the environmental impacts of marine coastal shrimp aquaculture". The ambiguity and lack of precise definition of this goal is indicative of the problem in rapidly achieving

²⁷ Presentation by DOF officer Siri Tookwinas 7 November 1994 at the Coastal Aquaculture Division, National Inland Fisheries Institute (NIFI), Bangkok, Thailand.

sustainable shrimp farming operations. A critical discussion of the effectiveness of these government policies is found in a Chapter 6.

Table 2.21 The Thai DOF twelve point plan (OEPP, 1994b)

-
1. Deepening the shallow ditches and canals.
 2. Reduction of production cost.
 3. Saltwater irrigation systems.
 4. Improved culture techniques.
 5. Designated shrimp culture zones.
 6. Quality control of shrimp larvae.
 7. Registration of the shrimp farmers.
 8. Control of feed quality.
 9. Control of chemicals and hazardous substances.
 10. Cooperation with the private sector.
 11. Measurements to determine the environmental impact of shrimp culture.
 12. Establishing effluent water quality standards for shrimp farms.

Table 2.22 Current Thai government position with respect to marine coastal shrimp aquaculture (Coastal Aquaculture Division, DOF, 1994)

-
- Limit total cultured area to 76,000 ha.²⁸
 - Conversion of traditional and semi-intensive culture systems to intensive culture.
 - Enforce the treatment of effluent water prior to release into receiving waters.
 - Implement sea-water irrigation systems in all major shrimp culture areas to increase the water quantity available and to improve that of effluent as well.
 - "Strengthening" of hatchery and farm registration to ensure shrimp product quality.
 - Establish a product investigation laboratory (1994) in every maritime province to investigate antibiotic residues before harvesting and sale to cold-storage operators.
 - Conduct research on marine shrimp spawner maturation in captivity to decrease the reliance on wild spawners.
 - Conduct shrimp genetic research to develop fast growing and disease resistant strains.
 - Conduct research on alternative species suitable for pond culture.

2.9.3 Specific regulations to address environmental problems

In 1992, the Thai DOF recognized that "the levels of nutrients, phytoplankton and suspended solids carried by shrimp farm effluent into the Gulf of Thailand may lead to polluted conditions that adversely affect aquatic resources and place the shrimp industry itself at risk". Therefore, in response to these concerns, on January 1, 1992 the DOF, Ministry of Agriculture and Cooperatives issued a ministerial decree requiring shrimp farmers to comply with the following regulations and provide a present day

²⁸ Total area cultured already exceeds this number and is said to be around 80,000 ha.

basis for siting of shrimp farms, waste treatment and environmental monitoring (Table 2.23). Regulatory compliance in Thailand is discussed in Section 6.

Table 2.23 Specific regulations formulated by the Thai DOF to address the environmental problems in shrimp farming (Ministerial decree issued by the DOF, Ministry of Agriculture and Cooperatives January 1, 1992)

-
- Shrimp farms and hatcheries **must** be registered.
 - Shrimp farms greater than 8 ha **must** be equipped with waste water treatment or sedimentation pond(s) of not less than 10 % of the rearing pond area.
 - For existing ponds, the retention pond **should** be completed before registration. The retention pond must be approved by the DOF before construction.
 - The BOD of effluent water **must** be below 10 mg/L and the Secchi disk transparency greater than 60 cm.
 - It is **prohibited** to release saline water into freshwater bodies or discharge of mud, silt or sediment onto public land or into natural water sources

2.9.4 Thai environmental impact assessment regulations

There are currently no requirements in Thailand for environmental impact assessments to be completed as a prerequisite for aquaculture site development. All indications are that shrimp farm development will eventually be recognized as an activity that requires EIA. The existing legislation stating the requirements for environmental impact assessment (EIA) are issued according to Sections 46 to 47, under the 1992 *National Environmental Quality Act* (NEQA). The Minister of Science, Technology and Environment with the approval of the National Environment Board (ONEB) has the power to issue the notification prescribing categories and magnitude of projects or activities of government agencies, state enterprise or private organizations, which are required to submit an EIA report. These reports are submitted to the Office of Environmental Policy and Planning (OEPP) and the Review Committee for consideration and approval before further proceedings. Reports received by the OEPP are the concern of the Environmental Impact Evaluation Division (EIED).

2.9.5 Thai procedures for the planning and development of coastal land

There are several institutions in Thailand responsible for the planning, development and implementation of policies with respect to coastal land for shrimp farming (Table 2.24). The DOF is the sole agency responsible for all three aspects of policy, planning and implementation. The institutional arrangements regarding the government departments responsible for coastal resources which affect shrimp farming areas is discussed in Chapter 6.

Table 2.24 Thai institutions responsible for the planning and development and implementation of policies with respect to coastal land for shrimp farming (Modified from Paw et al., 1988)

Government Agency	A*	B	C
National Environment Board (ONEB)		X	
Land Development Department (LDD)		X	
Royal Forestry Department (RFD)	X	X	
Department of Fisheries (DOF)	X	X	X
Department of Agriculture Extension (DAE)		X	
Department of Mineral Resources (DMR)	X	X	
National Economic and Social Development Board (NESDB)	X	X	
Interior Ministry (IM)	X	X	

Note: A-Policy; B-Planning; C-Implementing

2.9.6 Other laws related to the environment or shrimp farming

There are numerous other laws and regulations in Thailand which relate either to the environment or indirectly to the activity of shrimp farming (Table 2.25). These regulations may figure more prominently as the aquaculture industry matures and the government makes a more concentrated effort to improve the operation and management of all coastal zone uses, including shrimp farming.

Table 2.25 Summary of the laws and regulations pertaining to shrimp farming and the environment in Thailand (organized chronologically under particular areas of legislative concern)

National Policies and Plans
Economic and Social Development Planning Act B.E. 2517 (1974)
Conservation of the Environmental Conditions Act B.E. 2535 (1992)
Use of land
Land Utilization for Agriculture Act B.E. 2547 (1914)
Land Law B.E. 2497 (1954)
Land Reform Act B.E. 2518 (1975)
Land Development Act B.E. 2520 (1977)
The Industrial Act B.E. 2535 (1992)
City Planning Act B.E. 2535 (1992)
Water quality Control
Public Health Act B.E. 2484 (1941)
The Industrial Act B.E. 2485 (1942)
Feed Quality and Control Act B.E. 2522 (1979)
The Building Act (No date)
Shrimp Farming
The Fisheries Act B.E. 2490 (1947) (Amended by Acts of B.E. 2496 (1953) and B.E. 2528 (1982))
The Drugs Act B.E. 2510 (1967)
Feed Quality and Control Act B.E. 2522 (1979)
Utilization of Natural Resources
The Fisheries Act B.E. 2490 (1947) (Amended by Acts of B.E. 2496 (1953) and B.E. 2528 (1982))
The Forestry Act B.E. 2484 (1941)
The Natural Reserves Act B.E. 2507 (1964)
Additional Related Acts
Navigation in Thai Water Act B.E. 2456 (1913)
Cleanliness and Tidiness of the Country Act B.E. 2503 (1960)
The Minerals Act B.E. 2510 (1967)
Poisonous Substances Act B.E. 2510 (1967) (Amended 1973)
Factories Act B.E. 2512 (1969)
Announcement No. 286 of the Revolutionary Council (1972)
Enhancement and Conservation of National Environmental Quality Act B.E. 2518 (1975)
The Ground water Act B.E. 2520 (1977)
Building Construction Control Act B.E. 2522 (1979)
National Environmental Quality Act B.E. 2535 (1992)
Others (no date): The Provincial Authority Act, Municipal Government Act, Sanitary District Act, City of Pattaya Act, and the Bangkok Metropolitan Act

3. CURRENT STATUS OF AQUACULTURE PRODUCTION PRACTICES AND TECHNIQUES IN THE PROVINCE OF SAMUT SAKHON

3.1 Introduction

This section reviews the production practices and techniques utilized in shrimp farming operations located in the Upper Gulf province of Samut Sakhon. Much of the overview here is derived from the author's study of field conditions during the period September 1994 to April 1995 and through consultation and research at NACA. The author noted during this analysis that the production methods and management practices of shrimp farms varied 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 made it difficult to describe the exact practices involved in shrimp farming in Samut Sakhon.

Keeping the above in mind, however, the general characteristics of intensive shrimp culture farms in Samut Sakhon province are not much different from other operations in Thailand and abroad. Intensive shrimp culture involves controlling the pond where shrimp are raised so as to optimize the environment. In this type of shrimp culture, shrimp PL produced in hatcheries are stocked into ponds where the water has been fertilized to create an algal bloom. The water is aerated to maintain dissolved oxygen (DO), and replaced regularly to prevent the buildup of metabolic wastes. The shrimp are fed formulated diets made from imported ingredients to produce a rapid growth. Two crops a year are normally produced in such ponds. Yields from this type of shrimp farming can vary from 5,000 to more than 10,000 MT per hectare per year. In short, the intensive shrimp pond functions as a brackish water feedlot for shrimp.

The analysis presented in this chapter is based on direct field observation and data sources available at NACA in Bangkok.

3.2 Post-larvae shrimp sources and hatcheries

An abundant supply of healthy PL is essential to shrimp farming particularly as supplies of wild stocks are unpredictable both in terms of quality and quantity. The PL are supplied from hatcheries located in the provinces of Chonburi (66 %) and Samut Sakhon (34 %). The hatchery fry are produced in close proximity to the stocking ponds to obviate the necessity of lengthy transport and handling stress which ultimately allows for easier acclimation of the fry once introduced to the grow-out ponds. The fry cost \$US 6 per thousand and the average age at purchase is 17 days (OEPP, 1994b) (Table 3.1).

Table 3.1 Information on shrimp PL shrimp stocking of shrimp ponds for intensive culture operations in Samut Sakhon (OEPP, 1994b)

-
- Primary species: *Penaeus monodon*
 - Stocking density (PL/m²): 19 to 31
 - Age (days) when stocked in ponds: 17.14 (Range 12 to 20)
 - Hatchery location (%): Chonburi (66); Samut Sakhon (34)
 - Average price (\$US) per thousand: 6

3.3 Post-larvae quality and survival

Although farmers prefer 'disease free' PL they are generally unaware of the PL quality or disease disposition at purchase. Reports for Thailand indicate that 95 % of all *P. monodon* larvae sampled were infected with the Monodon baculovirus (MBV). To avoid this problem farmers obtain hyper saline water from salt pans which is relatively free of pathogens because of its high salinity. The survival rate of hatchery produced fry may be as high as 95 % (Suraswadi, 1990), however, it is usually between 40 % to 50 % in the small-scale hatcheries. This results in better survival rates in rearing ponds as weaker individuals have already perished (Csavas, 1990). Attempts by farmers to eradicate infected larvae are to switch species to more 'resistant' varieties. Some farmers have switched to *Penaeus japonicus* because of the latter's tolerance to Monodon Baculovirus (MBV). This was first attempted by Taiwanese *Penaeus monodon* growers. The success

of this practice has been limited and the overall reasoning for this switch will be discussed below.

3.4 Pond stocking density

Stocking density is dependent upon a number of factors including: pond size, supply water quality, type of culture operation and targeted production levels. Generally, the primary goal of most shrimp farmers is to achieve the highest possible production in the shortest period of time. Therefore, in many instances, ponds are initially stocked at very high densities with the intent to offset losses incurred later. Samut Sakhon farms utilized various initial stocking densities with the decision resting primarily with the individual farmers. The density reported to a NACA survey in 1994 ranged from 19 to 31 PL per meter squared (PL/m²) (Table 3.1). Farms in the sub-district Amphur Ban Phaeo¹ (i.e. sample Station 2) used much higher initial stocking densities that ranged from 52 to 94 (PL/m²) and the number of PL per hectare was 515,625 to 937,500 respectively (Table 3.2). For comparison, the normal stocking density for intensive ponds is 300,000 PL/ha.

Table 3.2 Pond stocking densities recorded at a low salinity intensive shrimp farm in Amphur Ban Phaeo, Samut Sakhon, Thailand, December 1994 to April 1995

Stocking density (PL/ha)	Density (PL/m ²)
937,500	93.75
515,625	51.56
937,500	93.75
750,000	75.00
625,000	62.5

¹ Amphur Ban Phaeo is a sub-district within the province of Samut Sakhon. In this sub-district there are currently 13 operating intensive shrimp farms and no semi-intensive or extensive operations (See Figure 6).

3.5 Pond preparation, treatment and sediment management

More than 90 % of the farms undertake pond bottom renovation, which is primarily sediment removal, after the grow-out pond harvest (OEPP, 1994b). Table 3.3 presents the methods of removal and percentage of use which included: either direct removal digging with a tractor (60 %) or manual removal (10%), chemical applications of lime (10 %), or pumping (20 %). The post-harvest pond bottom renovation of the accumulated sediments, prior to their removal, utilized sun drying methods which ranged from 29 to 34 drying days per crop. This range is interpreted as 34 drying days before sediment removal by digging, and 29 days if pumping methods were utilized.

Some farmers in the region employ a floating dredge that can either be used for accumulated sediment removal or partial harvesting of the shrimp crops during the grow-out cycle. Others use high pressure hose systems to expedite the removal of accumulated sediments and decreases the turn-around time between crops. This environmentally destructive practice has been outlawed in Thailand. The damage comes from the highly concentrated sludge that is suctioned from the ponds and then directly discharged either to irrigation canals or near-shore waters. There are potentially severe environmental problems resulting from discharge to the sea and the surrounding ecosystem. In addition, the hastening of crop rotation leads to more rapid onset of pond bottom deterioration, resulting from the lack of drying time. Figure 18 represents a typical shrimp farm in operation with the pond dikes and drainage canals in their final form. Figure 19 illustrates the machinery utilized to re-work the pond structures between crops, during pond construction or for sediment removal.

Table 3.3 Sediment removal methods (OEPP, 1994b)

Method	No. farms (n=50)	Percent (%)
• Digging with a tractor	30	60
• Digging manually	5	10
• Chemicals (i.e. lime)	5	10
• Pumping	10	20



FIGURE 18. A TYPICAL INTENSIVE SHRIMP FARM SHOWING POND AND DIKE STRUCTURES



FIGURE 19. HEAVY MACHINERY COMMONLY USED TO REPAIR OR MODIFY SHRIMP PONDS, REMOVE ACCUMULATED SEDIMENT AFTER DRY-OUT AND CONSTRUCT DRAINAGE CANALS

3.6 Aquaculture site descriptions

Information on sediment quality is difficult to acquire. A NACA survey in 1994 determined the soil quality of three abandoned shrimp farm sites in the province of Samut Sakhon (Table 3.4). It is difficult to assess the changes that have taken place as a result of shrimp farming when very few baseline studies exist. With respect to conductivity, the survey noted that the values are not normally higher than 2 mS/cm.

Table 3.4 Soil quality of abandoned Samut Sakhon shrimp farms measured at three different depths in three different locations (OEPP, 1994b)

Site	S1*			S2			S3		
	0-30	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90
Depth (cm)	0-30	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90
pH	6.23	7.10	7.46	6.86	6.85	6.99	8.16	8.21	8.24
Conductivity (mS/cm)	25.84	24.51	29.40	17.78	23.58	27.39	30.47	38.70	50.40
Organic matter (%)	1.64	1.67	1.86	1.74	1.72	1.87	0.85	0.66	0.66
Phosphorus (mg/kg)	122.1	148.3	193.0	103.0	108.3	92.3	120.4	131.9	143.6
Sulfate (mg/kg)	630	652	843	386	374	426	438	537	546
Calcium (mg/kg)	0.54	0.37	0.53	0.17	0.22	0.25	0.64	0.65	0.71
Magnesium (mg/kg)	1.51	1.04	1.54	0.65	0.82	1.07	1.10	1.40	1.86
Sodium (mg/kg)	20.39	19.29	20.60	14.95	18.83	20.75	32.85	34.12	43.03

Note: * The location of soil sample stations (S1, S2 and S3) could not be determined from the above reference other than a general description that they were collected from 3 of the farms surveyed by NACA in 1994.

Table 3.5 compares the effluent from intensively managed shrimp farms with the waters from pristine mangrove waterways. Ideally, aquaculture operations would utilize the benefits of intact mangrove systems without degrading the mangrove system's environmental characteristics. This has not been the case with respect to intensive shrimp farm developments in previous mangrove areas. This comparative information will figure prominently in afforestation efforts and provides relevant background information for discussion in Chapter's 5 and 6.

Table 3.5 Nutrient and particle concentrations and bacterial cell densities and production in effluent water from intensively-managed shrimp ponds (Robertson and Phillips, 1994)

Parameter	Intensive shrimp-pond effluent water	Pristine mangrove waterways
Salinity (‰)	10.0-35.0	0-37
NH ₃ (μM)	1.97-73.15	0.10-1.42
NO ₃ (μM)	0.05-1.54	0-11.75
PO ₄ (μM)	0.53-4.21	0-5.26
TSS (mg/L)	119-225	67-3312
Chl <i>a</i> (μg/L)	20-250	0.2-5.07
Bacterial numbers (cells/mL)	8.8-25.7*10 ⁶	0.85-4.70*10 ⁶
Bacterial production (μg C/l/day)	39-87	0-18

Note: For comparison, the range of values in pristine tidal and estuarine mangrove waters are provided. Data for the above, cited by Robertson and Phillips (1994) based on studies by Kanit and Putha (1992), Lin (1993), Alongi et al. (1992), and Robertson et al. (1993).

Table 3.6 compares the features of an abandoned shrimp farm with that of intact mangrove sites. The measured physicochemical differences are useful in describing the differences between the systems. For example, natural forest mangroves have significantly higher animal species (i.e. arthropods, molluscs, polychaetes) 9.00 versus 3.00, and animal densities (number/m²), 135.00 versus 16.00, than abandoned shrimp farms respectively.

Table 3.6 Comparative study of environmental factors and aquatic species in mangrove forests and in abandoned shrimp farms (Data from Gajaseni, 1982 and cited in Sanit, 1993)

Environmental Factors	Natural mangrove forest	Abandoned shrimp farms
Temperature (°C)	21.00-31.00	31.50-34.00
Soil moisture (%)	92.50-143.30	15.10-60.00
Soil organic content (%)	23.30-40.60	19.80-28.80
Soil nitrogen (%)	0.41-0.52	0.15-0.42
Soil phosphorus (ppm)	3.70-15.50	2.50-8.40
Soil potassium (ppm)	280.00-1180.00	176.00-1000.00
Animal species *	9.00	3.00
Animal density (No/m ²)	135.00	16.00

Note: * (Arthropods, mollusks, polychaetes)

3.7 Source water quality of shrimp farms

The coastal water quality of the province of Samut Sakhon was found to be unsuitable for shrimp culture (Table 3.7). The decisions regarding suitability are based on comparison to the standards for the quality of the coastal water as found in Appendix A-Table A.1. Water source quality of some other shrimp farming regions is found in Appendix B-Table B.5.

Table 3.7 Water quality of sea water resources for shrimp farming in 1992 for the province of Samut Sakhon (Modified from FAO/NACA, 1995)

Location	Bang Pakong River Mouth	Coastal area	Subpa Samit Canal Mouth	Subpa Samit Canal
Salinity (ppt)	0.0-32	5-36	22-32	18-32
pH	6.7-8.0	7.6-8.5	6.4-9.0	7.4-8.4
DO (mg/L)	4.1-8.8	1.1-11.8	1.1-7.5	0.3-7.5
BOD (mg/L)	ND	ND	ND	ND
Nitrite (mg/L)	0.005-0.122	0.1	0-0.05	0.0-0.18
Ammonia (mg/L)	0.072-0.702	0.2	0.007-0.32	0.044-0.46
Phosphate (mg/L)	0.00-0.05	0.25-3.0	0.01-0.48	0.02-0.13

3.8 Water supply and storage

The majority of shrimp farms intake water directly to the shrimp ponds while the remainder use storage reservoirs prior to pond stocking. Whether the water is initially directed to the shrimp pond or to a reservoir, most operations pass the water through a mesh filter prior to admission to the shrimp farm to remove undesired organisms and debris (Table 3.8).

Table 3.8 Water supply management on Samut Sakhon shrimp farms (OEPP, 1994b)

Details	No. farms (n=52)	Percent (%)
Water intake direct to pond	31	60
Filtered	(16)	(52)
Not filtered	(15)	(48)
Use Reservoir	21	40
Mesh filtered	(16)	(76)
Not filtered	(5)	(24)

3.9 Reservoir water chemical treatments and pond water analysis

A NACA survey in 1994 reported that farmers with reservoirs chemically treat the intake water with lime, chlorine, or formalin at different rates before utilizing the water in the grow-out ponds. The average residence time of the water in the reservoirs was 84 days and the average reservoir size was 3.8 ha. Farms culturing other aquatic animals in the reservoirs derived an additional income of up to \$US 1,415 /ha. Most farms analyze pond water quality daily (52%). The pH and the salinity of the pond water are the major parameters verified. Most of the shrimp farmers use some form of chemical treatment in the ponds (Table 3.9).

Table 3.9 Survey of 52 shrimp farms for chemical treatment and water quality analysis OEPP, 1994b)

Chemical treatment in reservoirs	
<ul style="list-style-type: none"> • Lime: 650 kg/ha/crop • Chlorine: 12.5 L/ha/crop • Formalin: 50 L/ha/crop 	
Chemical treatment in shrimp ponds (% and number of farms)	
Yes : 73 % (38)	No : 27 % (14)
Shrimp pond water quality analyzed (% and number of farms)	
Yes: 52 % (27)	No: 48 % (25)
Parameters analyzed daily: pH (72 %); Salinity (60%)	

3.10 Water exchange and wastewater disposal

Water exchange practices vary according to water availability and farm location. The shrimp farms with an easily access to a reliable water source or with enough farm area for a reservoir have the option of exchanging water more frequently. The primary purpose of water exchange is to improve pond water quality and to replace water lost through evaporative and seepage losses. The farmer attempts to maintain the water quality in the ponds between acceptable ranges for the safety of the shrimp crop and will exchange water as necessary to do so. In Samut Sakhon there was a wide range in the number of occasions upon which water exchange occurred (i.e. 1 to greater than 60) but the majority of farms exchanged water between 1 to 30 times per crop (69 %) (Table

3.10). The implications stemming from what type of water supply source is utilized, in regards to the overall risk to, or health of, the shrimp crop, are discussed below.

Table 3.10 Frequency of water exchange (OEPP, 1994b)

Exchange frequency (times per crop)	No. of farms (n=52)	Percent (%)
1-7	12	23
8-15	9	17
16-30	15	29
31-45	4	8
46-60	9	17
> 60	3	6

The current trends in the water supply and exchange practices of shrimp farms in the region indicate a significant decrease in the amount of water utilized during the culture period. Early intensive shrimp farmers often exchanged up to 40 % per day of the total pond water volume. Now many of the shrimp farming operations, especially in the Upper Gulf, do not exchange water throughout the entire culture period. The change in operating procedure can be attributed to the shrimp farmers wanting to reduce the risk of 'self-pollution' and disease transmission between shrimp farms located in close proximity, and to poor source water quality. As the safety of the shrimp crop is primary, farmers are willing to accept the complications that restricted water exchange creates. The eventual outcome of the practice may be the development of complete on-farm water recycling systems and wastewater recovery (closed cycle operations). The status, extent and implications of these developments are discussed in a later section. Wastewater effluent is discharged from operating shrimp farms to public waterways including irrigation canals, rivers and near shore coastal waters with virtually no treatment or recycle systems in place (Table 3.11).

Table 3.11 Disposition of wastewater discharges from shrimp farms (OEPP, 1994b)

Location	Number of farms (n=52)	Percent (%)
Sea	23	44
Public canal	18	35
River	11	21

3.11 Chemicals used for grow-out pond water

Shrimp farms in Samut Sakhon use a suite of chemicals in the grow-out pond consistent with other shrimp farming operations elsewhere. Usually these chemicals are added to

the ponds by broadcasting by hand in different quantities during all phases of shrimp production commencing during pond renovation before stocking PL and thereafter during the entire grow-out period. Primarily used to improve water quality (i.e. adjust/increase pH, turbidity, improve water color, etc.), they may also be applied to eradicate disease causing micro-organisms or kill predatory fish. Table 3.12 presents the common chemicals used in penaeid hatcheries and grow-out ponds (Phillips et al., 1993).

Table 3.12 Common chemicals used in penaeid hatcheries and grow-out ponds (Phillips et al., 1993)

Lime²: Calcium hydroxide ³ ; calcium carbonate ⁴ ; calcium oxide ⁵ (neutralization of acidity, sterilization of pond bottoms)
Piscicides and molluscicides (ponds): Teaseed cake (saponin, widespread use), calcium hypochlorite (<i>P. japonicus</i> ponds in Japan), derris root extract (rotenone, widespread use). Tobacco dust (nicotine, widespread), endrin, DDT, aldrin, thiodan (not recommended but still used in ponds in some countries), organotins (molluscicides in ponds)
Disinfectants, water and soil treatment: EDTA (hatchery, 5-10 mg/L, reducing metal toxicity), sodium hypochlorite (hatchery, 5 mg/L, common disinfectant), benzalkonium chloride (BKC) (pond, hatchery, disinfectant), zeolite (ion exchange resin, intensive ponds), potassium permanganate (ponds, occasional use), calcium carbide (sterilization of pond sediments especially for crab eradication)
Chemotherapeutants: Copper sulfate (ponds, algacide and anti microbial), malachite green (hatchery and ponds, fungal infections, in widespread use, 1-2 mg/L), formalin (hatchery and ponds, anti microbial, parasitic treatments, 25-250 mg/L), methylene blue (protozoa infections, 8 mg/L) and Antibiotics for control of bacterial disease, including chloromycetin, chloramphenicol (hatcheries, widespread use, although now banned in some countries), oxytetracycline (ponds, widespread use), oxolinic acid (rare), furazolidone, streptomycin, tetracycline, nitrofurazone.

Table 3.13 provides a chemical specific summary of application rates used by Samut Sakhon shrimp farmers (NACA survey in 1994 and reported in OEPP, 1994b).

² The chemicals used for liming of soils are the oxides, hydroxides and silicates of calcium or magnesium. The favorable results of liming the shrimp ponds include: killing microorganisms, raising the pH of acidic water, increasing the alkaline reserve in water and soil which prevents changes in pH, neutralizes sulfides and acids, promotes biological productivity since it enhances the breakdown of organic substances by bacteria creating more favorable oxygen and carbon reserves, precipitates suspended or soluble organic materials and improves fine textured bottom soil in the presence of organic matter.

³ Calcium hydroxide [Ca(OH)₂]: Also known as flaked lime, hydrated or builders lime. It is prepared by hydrating calcium oxide.

⁴ Calcium carbonate [CaCO₃]: Also known as agricultural lime. This is either calcitic limestone which is pure calcium carbonate or dolomitic limestone which is composed of calcium-magnesium carbonate.

⁵ Calcium oxide [CaO]: Also known as quick-lime, unslaked lime and burnt lime. This is the only compound to which the term lime may be correctly applied.

Table 3.13 Summary of chemical treatments in shrimp ponds (OEPP, 1994b)

- **Lime:** applied before and after stocking PL to increase pH and improve water color; application rate of 281.25 kg/ha thereafter when necessary
- **Teaseed cake (saponin):** applied before and after stocking PL and to kill predatory fish; application rate of 25 kg/ha; frequency of 1 time/crop
- **Zeolite:** applied to improve water color with an application rate of 187.5 kg/ha
- **Chloramphenicol:** applied after stocking PL to strengthen shrimp; application rate of 31.25 capsules/ha
- **Iron oxide:** applied before stocking PL to improve the quality of the pond bottom; application rate of 18.75 kg/ha
- **Other chemicals:** formatera , BKC , formalin and aformate : applied before and after stocking to kill fungi and viruses and to protect shrimp from disease; application rate of 12.5 L/ha; frequency of 1 time/crop;

3.12 Water quality decisions and how information is obtained

Even with the many information sources available, shrimp farmers in Samut Sakhon generally obtain the majority of their working knowledge from neighboring operations (Table 3.14). Obtaining this information from neighbors allows them to benefit from the experience of others, but also can be the reason for repetition of mistakes. Salespersons from chemical companies generally offer convincing reasons for chemical usage (i.e. increasing their commissions) without offering the full explanation of the potentially adverse effects of using these chemicals. The education level of most of the shrimp farmers does not allow them to challenge the advice of these 'knowledgeable' salespersons.

Table 3.14 Information and advice sources used by shrimp farmers regarding chemical use during grow-out operations (OEPP, 1994b)

Source	No. (n=38)	Percent (%)
Neighbor	28	74
Salesman	6	16
Technical papers	2	5
Technicians	1	3
Relatives	1	3

The common water quality conditions that arise in the shrimp culture ponds are high or low pH and/or salinity. For high pH or low salinity, most of the farmers exchanged the water, and for low pH, lime was applied (Table 3.15). Important decisions regarding improving shrimp farm performance are met by checking with neighboring operations for

advice. In some cases, farmers are reluctant to involve or seek outside information sources. In some cases this is to safeguard proven practices from their neighbors. This also applies primarily to larger company operations that are in the process of developing chemical prescriptions or new operating procedures.

Table 3.15 Water quality decisions made by shrimp farmers (OEPP, 1994b)

Condition	Decision	No. Farms (n)	Percent (%)
High pH n=15	Apply teaseed cake	1	7
	Change water	14	99
Low pH n=6	Apply lime	5	83
	Apply cows milk	1	17
Poor salinity n=10	Change water	9	90
	Leave it	1	10

3.13 Feeding practices (type, application rate and frequency)

The fate of excess feed released into intensive shrimp ponds has been well documented and is based primarily on the diet digestibility and the food conversion ratios achieved in the ponds, with high food conversion ratios being desired. Generally, after initial feeding 85 % is consumed and 15 % of the feed is lost to leaching (i.e. not consumed). The disposition of the 85 % once consumed by the shrimp is as follows: 48 % is excreted as metabolites, excess nutrients, ecdysis (molted shells) and maintenance (energy); 17% is harvested as biomass; and 20 % is excreted as feces (Primavera, 1994). The feeding practices of some intensive shrimp farms in Samut Sakhon are presented in Table 3.16.

Table 3.16 Feeding practices of some intensive shrimp farms in Samut Sakhon (Modified from OEPP, 1994b)

Feed type & month	Feeding rate (kg /time/ha)	Frequency (times/d)	Days
1: CP 902	8.1	3	30
2: CP 904	26.9	3	30
3: CP 905	38.1	3	30
4: CP 905	36.3	3	15

Based on the high cost of feed, in excess of 60 % of the farm operating cost, there is a significant loss of revenue through wastage and improper feeding practice. Therefore, the management of feeding practice is highly important (Wang, 1990). As mentioned, improper feeding practice contributes to pond bottom deterioration, especially in Samut Sakhon ponds where water exchange practices are restricted due to risk to the source

quality. In Samut Sakhon the reported total expenditure per hectare for a 3 month culture period was \$US 1,200 and for a 6 month culture period was \$US 1,460 (OEPP, 1994b).

3.14 Pond production cycle and grow-out period

The normal culture period for one crop in a grow-out pond in Samut Sakhon is around four months (120 days). The shrimp farmers can generally culture two crops per year. This number varies with the rotation time between crops (i.e. the pond bottom drying or pond renovation time) and seasonal constraints (i.e. conditions of the wet or dry seasons). Most farmers experience water management problems (quality and quantity) during the dry season (i.e. too high salinity) or rainy season (i.e. too low salinity). These climatic extremes affect decisions regarding the production cycle. Farmers overcome these seasonal constraints by planning crop rotations so as to occur during the transitional periods (i.e. between the dry and rainy seasons).

3.15 Pond yield and survival rates

There is little information relating the production yields and crop survival rates at the pond-level. However, an examination of provincial production statistics and the area under culture gives some of this information. Table 3.17 indicates the average mortality of the *P. monodon* as well as some other commercially important species in Thai coastal aquaculture operations.

Table 3.17 Average mortality rate by species in Thai coastal aquaculture operations (Data from the diseases and parasites section of the Brackish water Fisheries Division, National Inland Fisheries Institute (NIFI), Bangkok, Thailand)

Species	Age (days) and average mortality rate (%)
Black tiger prawn (<i>Penaeus monodon</i>)	3-25 (40 %) (at hatchery); 30-50 (55 %); 90-100 (15 %)
Seabass (<i>Lates Calcarifer</i>)	1-15 (60 %); mature (23 %)
<i>Epinephelus</i>	larvae (40 %); mature (20-40 %)
Pacific Oyster (<i>Crassostrea gigas</i>)	- / 80
Mud Crab (<i>Scylla serrata</i>)	larvae (70 %); mature (25 %)

3.16 Occurrence of disease and its in relation to water source supply

Several comprehensive reviews of the agents that cause disease in penaeid shrimps, and their respective treatments have been completed (e.g. see Flegel and Sriurairatana, 1993; Lightner, 1988; Liu, 1989; and Brock and Lightner, 1990). Disease is the almost inevitable consequence of poor water quality and adverse pond bottom conditions. The intensification of culture methods escalates the risk of infectious disease, which in the best case scenario, can be treated at the expense of increased production costs, or in a worst case scenario can lead to devastating losses (Clifford III, 1992). It has been estimated that disease cost the Asian aquaculture businesses US\$ 1.36 billion in 1990. As aquaculture production grows, the danger looms larger (Anon., 1994b). Viruses present a serious threat to the global shrimp farming community. Flegel and Sriurairatana (1993) identified the shrimp diseases that affect shrimp in Thailand (Table 3.18).

Table 3.18 Shrimp diseases reported in Thailand (modified from Flegel and Sriurairatana, 1993)

-
- **Viruses:** Monodon baculovirus (MBV); Yellow-head baculovirus (YBV); Lymphoid organ virus; Infectious hematopoietic and hypodermal necrosis virus (IHHNV); and Hepatopancreatic parvo virus (HPV).
 - **Bacteria:** Vibriosis in the grow-out shrimp; Vibriosis in the hatchery larvae; and Other bacteria (Aeromonas, sessile/filamentous bacteria)
 - **Fungi:** Oomycetes (e.g. Lagenidium); and Other fungi (e.g. Fusarium)
 - **Parasites:** External parasites (Protozoans: Zoothamnium, Epistylus, Vorticella and Acineta); and Internal parasites (Microsporidian: Agamasoma penaei)
 - **Environmental factors:** Pesticides (e.g. methyl-parathion, cypermethrin-used by rice farmers to eradicate fresh water crabs that attack rice seedlings); Toxic algae (Dinoflagellates, blue green algae and some diatoms); Crude oil; waste water and pond bottoms.
 - **Mysteries:** Larval black spot syndrome; Spongy tissue syndrome; Brown muscle syndrome (Idiopathic muscle necrosis or IMN); and One month Mortality Syndrome (OMMS) (one to six weeks after stocking).

Protection of coastal environmental quality is imperative in order to avoid disease problems within the shrimp farming industry. Jiang (1994) reported that 50 % of captured *Penaeus monodon* were found to be infected by viruses. However, only when environmental conditions are aggravated, are pathogens activated and induced. Barg (1992) schematically represented the relationship between the grow-out pond, disease and the environment. The reasons for sudden increases or changes in disease patterns are predisposing environmental factors (Browdy et al., 1995).

Through a detailed assessment of shrimp farms in various regions the present researcher noticed that the location of the farm in relation to water sources may predispose the shrimp farm to disease problems (i.e. disease and location are related). Table 3.19 presents the value (\$US/ha/crop) and number of farms (%; n=) reporting losses from disease in the southern Thailand provinces of Hua Sai and Ranot (OEPP, 1994a). Although the same percentage of farms reported disease problems for both location types the farms located close to canal water sources incurred greater financial losses. An examination of the farm locations in Samut Sakhon, with access only to inland irrigation canals and shallow estuary water sources, are negatively predisposed. By virtue of these constraints Upper Gulf farms must use the same water source for supply and discharge conditions. New farms constructed in the southern and eastern shrimp farming regions have recognized this problem and constructed operations, where possible, to use separate water delivery and disposal arrangements.

Table 3.19 The value (\$US/ha/crop), number of farms (%) and number of operations (n=) reporting losses from disease in southern Thailand provinces of Hua Sai and Ranot (OEPP, 1994a)

Disease	Close to the sea		Close to the canal	
	Value	% (n=)	Value	% (n=)
Yellow head	21,962	16.7(4)	39,871	43.8(7)
One-month mortality syndrome	7,163	25.0(6)	6,636	12.5(2)
Swollen gill	0	29.2(7)	17,665	12.5(2)
Black gill	4,103	12.5(3)	33,420	12.5(2)
Red body	1,910	4.2(1)	8,101	25.0(4)
Other	NA	8.3(2)	NA	6.3(1)
Have disease problem YES/NO	75.0 (18)/ 25.0 (12)		75.0 (12)/ 25.0 (4)	

The quality of the water supply (Table 3.11) and the main diseases reported (Table 3.20) are known. However, the survey of Samut Sakhon did not include determining the frequency and number of disease problems with respect to location.

Table 3.20 Diseases reported from Samut Sakhon shrimp farming areas in 1994

Disease	No. of farms	Percent (%)
Yellow Head	10	20
Black Gill	12	24
Algal growth on shell	5	10
Tail rot	10	20
Molting Problem	2	4
Black Muscle	6	12
Other	4	8

3.17 Status of income, investment and profitability

Shrimp farming operations require a high initial investment which may provide a significant return or a significant loss. The potential for significant economic returns is linked to the occurrence of disease during grow-out. This potential for significant returns is a driving factor in the rush to develop shrimp farms. It is common knowledge, although seldom documented, that investments can be fully recovered from profits received from less than two crops of shrimp, that is, in less than one year in a tropical country. This feature has continued to lure increasing numbers of investors, few of whom are familiar with aquaculture or farming in general. The continuing failure of shrimp crops in the Upper Gulf has revised the above comments regarding the potential for income and profitability. Methods to improve sustainability including income and profitability are discussed in Chapter 6 with possibilities for either re-introducing shrimp farming operations or commencing other revenue generating land uses (other than abandonment).

3.18 Number of farms and area cultured in Samut Sakhon (and Thailand) prior to intensification

The Upper Gulf provinces, including Samut Sakhon, were the favored provinces for the establishment of shrimp farms in Thailand (Table 3.21).⁶ As of 1969, there were 938 shrimp farming operations in Thailand covering an area of 6,732 ha in 7 coastal provinces and yielding some 3,440 MT of crustaceans. The majority of these farms were located in the province of Samut Sakhon which had a total of 464 operations and 2,745 ha of the total farmed area (Tiensongrusmee, 1970). These early farms, which consisted of converted salt ponds and rice paddies, experienced large fluctuations in yield ranging from 250 to 900 kg/ha. During the 1970's production techniques and volume did not change significantly and as of 1980, cultured shrimp production was still not more than 8,000 MT (Csavas 1994a). The situation would later change as the conditions for the rapid growth of shrimp farming were established.

⁶ In some cases referred to as the 'cradle' of shrimp culture in Thailand.

Table 3.21 Number of farms and area engaged in shrimp farming in 1969 in Thailand (Tiensongrusmee, 1970)

Province and Tambon	Number of farms	Farm area (ha)
Samut Sakhon	464	2,744.8
Bangtorad	36	30.6
Bangkrachao	49	112.5
Banbao	43	79.4
Bangyaprag	46	222.4
Bangrai	70	652.3
Galong	43	223.2
Kogkham	124	750.6
Nakog	50	662.4
Pantainorasing	3	11.4
Samut Prakan	377	2,898
Thonburi	56	790.7
Chanthaburi	19	129.1
Rayong	3	17.3
Nakhon Si Thammarat	10	80
Pattani	9	72
Total	938	6,731.80

3.19 Number of farms, area cultured and district location

In 1992 there were only 1,150 farmers as compared to the peak recorded number of 2,295 in 1989 (OEPP, 1994b). The above total for 1992 included 1,039 extensive, 25 semi-intensive and 86 intensive operations. The total area cultured was 7,072.6, 148.3 and 147 ha respectively. As Table 3.22 indicates Kogkham and Pantainorasing, located in Amphur Muang, were the busiest sub-districts in the province (DOF, 1994a).⁷ A survey by NACA in 1994 determined that the majority of farms in Samut Sakhon were privately owned and operated (88 %) and the remainder were partnership operations (12 %) (OEPP, 1994b). The production from these farms was presented in Chapter 2 with the Upper Gulf of Thailand section.

⁷ This is the most recent year for which official data are available from the Department of Fisheries, Bangkok.

Table 3.22 Culture area, number and type of farms for the province of Samut Sakhon by district and sub-district in 1992 (DOF, Bangkok, 1994)

Location	Number of farms			Area (ha)		
	E*	S	I	E	S	I
Amphur Muang	1,039	25	73	7,072.7	148.3	147
Chiang Mong Kol	-	-	2	-	-	4.3
Banbao	58	-	14	321	-	16.3
Bangkprag	79	-	2	696	-	32
Groc Grak	-	-	22	-	-	27.5
Ta Charoen	-	-	15	-	-	19.8
Kogkham	315	18	-	1,754.1	106.2	-
Bangkrachao	25	1	3	192.3	4	2.1
Thachin	4	1	7	26.4	6.4	7.8
Galong	35	1	1	314.1	8	1.9
Nakog	32	1	3	357	1	23.8
Bangtorad	43	2	3	488	18.7	8.6
Pantainorasing	448	1	1	2,923.8	4	2.9
Ban Phaeo*	-	-	13	-	-	27.2
Pong Kae	-	-	13	-	-	27.2
Total	1,039	25	86	7072.7	148.3	174.2

Notes:

1. E-Extensive; S-Semi-intensive; I-Intensive
2. In Ban Phaeo there is only one sub-district with shrimp farms (Pong Kae) and all of the farms operate as intensive operations.

4. METHODOLOGY FOR FIELD INVESTIGATION

4.1 Introduction

The field investigation was completed during an eight month visit to the Network of Aquaculture Centers for Asia-Pacific (NACA) from September 1994 to April 1995. Previous background research was conducted during a four month visit to NACA from September 1993 to December 1993.

Primary field data was collected in the province of Samut Sakhon during bi-weekly repetitive sampling of 5 stations from 7 December 1994 to 5 April 1995. The data collected from the five stations included the following parameters: physical and chemical (Table 4.1), inorganics (Section 4.8), plankton (Section 4.9), organics (Section 4.10) and heavy metals (Section 4.11). The collected samples were analyzed during the period between field visits with assistance and permission of the National Inland Fisheries Institute (NIFI) located on the Kasetsart University campus, Bangkok, Thailand.

Experience from this field study has demonstrated that it is not easy to choose the optimum level of environmental data needed to generate the sustainability assessment required for the specific goal and objectives of this research. The idea in this field study was not to generate extensive data sets which are difficult to obtain in remote locations. Rather the intent was to collect data that would lead to an understanding of the challenges in maintaining the biophysical quality of shrimp farming areas in the province of Samut Sakhon.

Access to the central laboratory of the National Inland Fisheries Institute, located on Kasetsart University Campus in Bangkok facilitated data analysis. This laboratory contained the necessary equipment and personnel to conduct standard methods of analysis. Data processing, primarily by manual methods, was verified in all cases.

4.2 Location and description of field sample stations and schedule of sample collection

Chapter Two presented a detailed biophysical description of the field study region. The selection of sample stations for this field investigation coincided with sites regularly sampled by the DOF. Their location within the province of Samut Sakhon is indicated on Figure 6. Sampling site names refer to the closest known geographic location. The five sampling stations were as follows:

Station One - Pitthayalongkorn canal (large canal)

The site was considered to be representative of a coastal water quality source by the DOF *although located 1.5 kilometers from the coast*. The 27 km canal connects the Thachin river in Amphoe Muang¹ Samut Sakhon to the Chao Phraya river near Bangkok. The canal is utilized for many purposes including the shipping and transportation of goods and personnel and green mussel stake culture operations. The canal receives the runoff and effluent from upland activities including agricultural, salt and shrimp farming operations. The canal is in free communication with the Upper Gulf and with the Thachin river. Many of the derelict shrimp farms are now located along its shores.

Station Two - Intensive low-salinity shrimp pond

A low salinity intensive shrimp farm operation situated more than 10 km from the coast in Amphur Ban Phaeo, Tambon Longkai. This farm is located in a supra-tidal area of low shrimp farming density but high agricultural activity (i.e. fruit farms, coconut plantations and mushroom farms). The farm discharges brackish water effluent to the fresh water canal system near a branch of the Klong Kok Canal. This adverse practice is in direct conflict with agriculture operations in the region dependent upon freshwater from the same canal. This farm has experienced success in shrimp culture at this location. Neighboring farms in the same district experienced crop failures during the field investigation.

¹ Amphur Muang is the main sub-district of the province of Samut Sakhon.

Station Three - Canal Promdan (Small Canal)

This brackish water canal is located in Amphur Muang, Tambon Nakho on the border between the provinces of Samut Songkhram and Samut Sakhon (beside Wat Prommalat). The canal transits an area of low-density shrimp farming but the canal is heavily populated and utilized for transportation and commuting purposes.

Station Four - Traditional extensive shrimp pond

Station Four was an extensive shrimp farm close to the coast. This extensive pond is supplied by Canal Promdan. The canal systems that supply this pond are small and inadequate for the volume of water desired. The surrounding environs are undergoing major land use changes which include the conversion to salt farming operations and urban development. The salt farms are being established on previous intensive shrimp farm sites.

Station Five - Mouth of Thachin river

A brackish water river source near the mouth of the Pitthayalongkorn Canal. This station is in free communication with the Upper Gulf. The sample station is located in Amphur Muang, Tambon Bangyapet (beside Wat Sisutharam). This river is the main drainage of all upland activities of the province of Samut Sakhon.

Schedule of collection

The field visit schedule resulted in a total of eight sample collections for Station's 1, 2, and 3. Only 6 and 7 sample collections were conducted at Station's 4 and 5, respectively. Organic and metal contaminants were only sampled twice at each of the stations, at the end of the wet season (start of fieldwork), and at the start of the dry season (end of fieldwork). Station 5 was sampled only once for analysis of metals and organics. The above differences are due to limitations in access to the sample stations on some sampling dates.

4.3 Secondary data collection

Secondary data was utilized to complete a detailed technical literature survey that examined the following: biophysical description of the study region, world shrimp production characteristics, historical development, description of the biophysical resources required for shrimp farms and associated environmental impacts. This data was utilized to develop an understanding of the present status and future development trends of coastal aquaculture for Samut Sakhon, as well as other coastal environments where aquaculture occurs. Chapter's 2 and 3 have presented this information.

Secondary data sources included:

Socioeconomic: Socioeconomic data was collected from the Department of Community Development, Department of Land Development, Department of Agricultural Extension and the Institute of Scientific Research and Technology of Thailand.

Oceanography and hydrography: Oceanographic data included the characteristics of the sea bed, tides, water currents, winds and the quality of water in the coastal areas and was obtained from the Department of Naval Hydrography. Data on rivers and canals was obtained from the Department of Irrigation.

Meteorology: Meteorological data collected included rainfall, temperature, and the relative humidity. This information was obtained from the Department of Meteorology and from the respective domestic meteorological stations in the study areas.

Shrimp culture: Shrimp culture data, including production and marketing statistics, were collected from various sources which included: Division of Coastal Aquaculture, Fisheries Statistics Section, Bangkok; National Institute of Coastal Fisheries Resources, Songkhla; DOF; Department of Customs; Prince of Songkhla University; Department of Agricultural Extension and the Office of Agricultural Economics in addition to data obtained in ongoing collaboration at NACA.

4.4 Primary data collection

Primary data collection was necessary to supplement the analysis of the secondary data. The primary data was collected from the important coastal environments in Samut Sakhon including the open coastline, river and estuaries, and coastal canals. There were two components to the primary data collection: the collection of environmental data through detailed and regular water sampling of coastal aquaculture sites; and direct observations at Samut Sakhon shrimp farms, to assess environmental impacts of current practices.

The investigation of 'water quality' assisted in determining the inherent physicochemical and microbiological characteristics of the water sources available to Samut Sakhon shrimp farmers. Suitable limits for healthy shrimp production in the grow-out pond have been established and are used in a comparison with levels recorded in the field sampling program. Appendix A contains all established standards for comparison.

Samples for this research were concurrently collected with an ongoing sampling program of the DOF. The co-operative arrangement allowed for direct observation of monitoring methods and increased access to information and field sample sites. Sample treatment and storage used conventional methods for storage in the field and transport to the laboratory. Many of the important aquaculture parameters could be measured *in situ* (e.g. pH and DO and were therefore, easily and reliably measured with locally available equipment.

4.5 Collection, storage and preparation of samples

All samples were collected using good quality pre-cleaned NALGENE™ high density polyethylene (HDPE) 1,000 mL capacity sample containers with a screw type lid. Samples were transported to the laboratory as quickly as possible and kept out of direct sunlight using a portable cooler stocked with ice while in transit. Since complete stabilization of the sample was impossible, analyses were made as soon as possible after collection. With the exception of *in situ* measured values and plankton samples, no sample preservation techniques were utilized. Sample collection containers used for

pesticide and heavy metal samples were thoroughly cleaned and prepared according to established protocols prior to use for field sampling (See Chapman, 1992).

4.6 Primary data collected for laboratory analyses

Collected samples were analyzed according to the procedures and guidelines outlined by Water Quality and Pond Soil Analyses for Aquaculture (Boyd and Tucker, 1992) which are primarily based on the standard reference work on water quality analysis which is the Standard Methods for the Examination of Waste and Wastewater (American Public Health Association *et. al.*, 1989). Other useful information sources consulted were Strickland and Parsons, 1972; Stirling, 1985; Boyd, 1992; Chapman, 1992 and Davis and Simon, 1995.

The laboratory analyses for the chemical contaminants measured in this fieldwork may be divided broadly into three groups on the basis of storage requirements and analytical techniques: organics, inorganics and metals. The collection and analysis methods for each group are now discussed.

4.7 Collection of samples and analyses of physical and chemical parameters

The field sampling program involved the collection of physical and chemical parameters at each of the sample stations *in situ*. Table 4.1 presents the parameters collected and the equipment used.

Table 4.1 Physical and chemical parameters sampled and equipment used *in situ*

Physical:	Secchi disk depth (cm)	Secchi disk ²
	Depth (m)	Depth gauge
	Air and water temperature (°C)	Mercury thermometer
Chemical:	Salinity (ppt)	"ATAGO" Hand Held Refractometer
	pH	pH meter - "Micro pH-PAL" ³
	Dissolved oxygen (DO) (mg/L)	DO meter - "YSI Model 57"

4.8 Collection of samples and analyses of inorganic constituents

Water samples were collected to analyze the following inorganic constituents: nitrate-nitrogen (mg/L) NO_3^- , nitrite-nitrogen (mg/L) NO_2^- , ammonia (mg/L) $\text{NH}_3\text{-N}$, orthophosphate (mg/L), total suspended solids (g/L), and chlorophyll *a* (mg/L). All of the above parameters were analyzed *in situ* by field kit and in the laboratory with the exception of total suspended solids and Chlorophyll *a*. The field kit allowed rapid determination (low in precision and sensitivity) and the laboratory methods allowed precision and sensitivity.

Samples were analyzed in the laboratory according to procedures outlined by Boyd and Tucker, 1992. The quantification techniques included titimetry and spectrophotometry. In the titimetry, the compounds were analyzed by observing the end point of its reaction with a reagent; this end point was associated with a color change. In the spectrophotometry, the compounds were chemically converted into color sensitive compounds that could be detected with a spectrophotometer. Concentration was determined by comparison of the color intensity with standards.

² Transparency values were determined by measuring the depth in centimeters at which a black and white disk (called a Secchi Disc) was just visible when it was lowered vertically into the water.

³ Accuracy of +/- 0.2 pH; operating temperature range 0-50 °C; resolution to 0.1 pH in the scale from 0 to 14. Glass bulb electrode sensor with automatic temperature compensation that could be adjusted by an offset trimmer.

4.9 Collection of samples and analysis of plankton

The sampling technique utilized the collection and direct enumeration of 1 liter volume samples at Stations 1, 3 and 5 according to the procedures described by Stirling (1985). This collection targeted larger plankton using a coarse mesh net. The collected samples were fixed and preserved using a 10 % formalin solution and stored in an ice filled cooler until laboratory analysis.

Special apparatus required for the enumeration procedure were a Sedgwick-Rafter counting cell, compound microscope (with a mechanical stage, 15 power eyepiece fitted with a Whipple ocular micrometer grid disc, and a 10 power objective) and a stage micrometer. The results are reported in cells/liter units and are found in Appendix C and discussed in Chapter 5.

4.10 Collection of samples and analyses of organic contaminants

Two samples were collected to investigate pesticide levels at the sample stations. Sample preparation, extraction and analysis was performed according to procedures outlined by Sukasem (1989). This procedure used gas chromatography and high performance liquid chromatography to identify the pesticides. Preparation of the samples for analysis involved the extraction of the organic compound into an organic solvent. Once completed, the sample was then introduced into the chromatography equipment. Although these substances are relatively insoluble in water, the vast majority are highly persistent in nature and are retained in sediment. Standards for such compounds in water and sediment are often based on toxicity to fish.

4.11 Collection of samples and analysis of heavy metals

Two samples were collected to investigate the heavy metal levels of cadmium, zinc, lead, copper and mercury. The sample preparation, elemental metal extraction and analysis was performed according to procedures outlined by Sukasem (1989). The values were

quantified using atomic absorption spectroscopy. In the sample in which the metal complex was suspected, the metal was first converted to its elemental form, by digestion with a concentrated acid. The resultant acidified sample was then injected into the sample chamber of the atomic absorption spectrophotometer, where it was vaporized and analyzed.

The equipment used for quantifying the cadmium and lead samples was the AA-680 SHIMAZU AA/flame emission spectrophotometer and for zinc and copper the GBC 932 AA graphite furnace was used. Metals, particularly heavy metals, can be highly toxic when ingested by humans or aquatic organisms. Standards are set on the basis of toxicity to living organisms (Appendix A).

5. RESULTS OF THE FIELD INVESTIGATION

5.1 Introduction

The results of the field investigation highlight the difficult and specific resource management problems concerning the utilization of coastal habitats for shrimp farms, associated water quality issues and the choice of appropriate locations for shrimp aquaculture farms. The results indicate the water source quality available to the Samut Sakhon shrimp farms including information on the level of organics and metals as well as the water quality within the grow-out ponds. Sample stations were representative of different water systems as follows: **One** (Large canal-SS1); **Two** (Intensive shrimp pond-SS2); **Three** (Small canal-SS3); **Four** (Extensive shrimp pond-SS4); and **Five** (Mouth of the Thachin river-SS5).

The water sample results from these stations provide information related to physical and chemical parameters, the level of organic, inorganic and heavy metal contaminants. All of the sampled parameters, with the exception of organics and metals, are important during the shrimp grow-out and must be kept within ranges suitable for shrimp. If this information is made available to the shrimp farmer, adjustments to the system can be made in an attempt to improve the pond environment.

The results of this field investigation were compared to Thai standards and other values determined to be suitable for intensive shrimp culture (Appendix A). Data collected during previous investigations of intensive shrimp farms including the water quality of provincial rivers was used for comparison (Appendix B). A full presentation of the data and results from this field investigation is found in Appendices D and E. The data adds to the total database on the water quality of shrimp farming areas in the province of Samut Sakhon. The sample program was part of an ongoing field study by the Samut Sakhon Coastal Aquaculture Development Center.¹

¹ With the exception of plankton enumeration, the author has been unable to compare data with that collected by the Samut Sakhon Coastal Aquaculture Development Center as of this date. It is hoped to do so in the near future. This would improve the data collected from this field study. The data has been requested on several occasions, beginning on 15 January, 1995.

The author determined that the most valid representation of the data (physical and chemical, inorganic and organic) was the mean and range values. Other statistical values determined were: standard error, standard deviation, sample variance (See Appendix E). Owing to the small sample population of the metals and organics, no statistical analysis was performed on these data.

5.2 Results of physical and chemical parameter analysis

Table 5.1 presents the results of the analyses of the physical and chemical parameters sampled during the field investigation.

Table 5.1 Physical and chemical parameter results (mean and range) for five sampling stations visited from 07 December 1994 to 05 April 1995 in the province of Samut Sakhon, Thailand

Variable	One (n=8)	Two (n=8)	Three (n=8)	Four (n=6)	Five (n=7)
SDD (cm)	25±35	16±15	25.6±85	27.5±25	45.7±60
Depth (m)	3.8±1.2	1.3±0.8	1.1±0.9	0.9±0.5	3.1±1.8
Air T (°C)	30.2±4.5	31.3±2.5	31.7±4	31.5±2	30±2
Water T (°C)	28.7±4	30.1±5	30.5±6	33±6	29.7±5
Salinity (ppt)	27.9±12	10.3±9	26.3±6	27.7±9	21±11
pH	8.1±1.1	8.4±0.8	8.0±1	8.3±0.9	7.8±1
DO (mg/L)	4.1±1.7	7.6±4.4	5.8±3.3	8.1±3.9	3.8±3.4

Notes: 1. Supporting data and results is found in Appendix D and E respectively.
 2. Description of Sample Stations: One (canal); Two (intensive pond); Three (canal); Four (extensive pond); Five (Thachin river). 3. SDD = Secchi disk depth.

The Secchi disk method is a convenient and cost effective way of assessing the transparency of a water body. Almost all shrimp farmers use Secchi disks in their culture ponds. The values for Secchi disk depth are affected by two basic types of turbidity in the water column: (1) that resulting from phytoplankton blooms, and (2) that caused by suspended soil particles. Both restrict light penetration into the water. Turbidity from the phytoplankton bloom is much more desirable.

The transparency of the water depends on the concentration of suspended solids, particularly the level of phytoplankton in the water, and is inversely related to the turbidity. It determines the conditions of availability of light in the water column to support photosynthesis by phytoplankton, and hence primary production. The

information can be used to calculate the compensation depth, or euphotic limit, at which gross primary production by photosynthesis of phytoplankton just balances respiratory losses. The compensation depth is normally defined as the depth at which the irradiance is 1 % of the surface value, and normally varies between 2 to 3 times the value of the Secchi disk depth. Thus, the importance of this value lies in being able to discern whether the water column is productive, and is particularly useful for aquaculture operations.

Studies conducted by Almazan and Boyd (1978) compared Secchi disk visibility in fish ponds with data on Chlorophyll *a*, particulate matter, and phytoplankton counts. The highest correlation was for particulate organic matter. The result is not surprising given that the count includes living zooplankton and phytoplankton as well as dead organic particles.

The plankton abundance is an indication of the water quality and nutrient content of the water. A water source with a high transparency is an indication that the nutrient content of the water is low. Different transparency levels result in different considerations for managing the shrimp pond water. For example, if light can reach the pond bottom, algae may grow to higher densities and restrict shrimp from burying themselves in the pond bottom. Also, in the pond environment there is a CO₂/anoxic issue that must be clarified. Even though photosynthesis absorbs CO₂ and releases O₂, the overall system can be net oxygen consuming. In this situation, the high densities of algae that die-off and accumulate in the pond, utilize the available oxygen and produce carbon dioxide. High concentrations of these parameters pose a risk to the shrimp crop, creating water management concerns for the shrimp farmer. The optimal transparency in a culture pond is reported to be 40 to 60 cm (OEPP, 1994a). The Thai water quality standard indicates that the value should not differ more than 10 % from this normal value (Appendix A-Table A.2). The values of Secchi disk depth are site specific, and farmers generally do not record the measured values. The information is used to monitor grow-out pond productivity, and to make practical adjustments as necessary to keep within desired limits.

The lowest Secchi disk values were recorded at the intensive shrimp pond (SS2) at 16±15 cm, and the highest value was measured at the mouth of the Thachin river (SS5) at 45±60 cm. With the exception of SS5, all of the measured values were less than the recommended 40 to 60 cm value for culture ponds. All values were more than 10 % out

of the range. The range of the values (highest in Canal Promdan) are indicative of the high turbidity of the Upper Gulf water courses. The wide range in Canal Promdan was attributed to the effects of tidal change which caused high amounts of loose sediment to move in the small canal where the sample was taken. The variability dictates that when shrimp farmers intake water to the culture ponds or reservoirs they must consider the turbidity of the water column. The amount of settling time required may be increased. With respect to the intensive shrimp pond (SS2) however, the increased feeding rates and stocking densities resulted in a high level of nutrients, phytoplankton and organic matter in the ponds - thus lowering the Secchi disk values.

The Secchi disk depth measured in this research is not a suitable estimate of plankton density in all cases. The most practical application of this data would be towards the management of the culture pond water at the intensive shrimp pond.

The water depth, in meters, was measured for all of the sampling stations. The depth at SS2 was 1.3 ± 0.8 m and for SS4 was 0.9 ± 0.5 m. The values recorded at SS2 and SS4 were consistent with the minimum water depth normally maintained for intensive shrimp ponds of 1.20 m and 1.0 m or less for traditional or extensive shrimp ponds (Table 2.1). The depth of extensive ponds is usually dependent upon the existing impoundments and the tidal range. Other depth values recorded for the canals and river sample station indicate the relatively shallow nature of these water systems in Samut Sakhon. They are susceptible to accumulation of sediment and are routinely dredged to deepen them for improvement of water supply and maintaining navigation.

The recorded air temperatures ($^{\circ}\text{C}$) at all stations were in the ranges expected for the time of year. The provincial air temperature range recorded previously by the Meteorological Department was 25 to 29 $^{\circ}\text{C}$. The water and air temperatures recorded during the sampling period were lowest during the start of the sampling program coinciding with the end of the wet season and highest during the April, the start of the dry season. The highest air temperature was recorded at SS3 31.7 ± 4 $^{\circ}\text{C}$ and the lowest at SS5 30 ± 2 $^{\circ}\text{C}$. A previously study of the lower Thachin (i.e. SS5) measured a temperature range of 29.4 to 31.63 $^{\circ}\text{C}$. The Thai aquaculture standards indicate that water temperature should not exceed 33 $^{\circ}\text{C}$ and a suitable level suggested by various sources is the range 28 to 33 $^{\circ}\text{C}$. All of the recorded values from the sample stations fell within these limits.

Salinity variation is a determinant factor in shrimp production with the optimum level for *Penaeus monodon* being 15 to 25 ppt. The Thai salinity standard for aquaculture indicates that the measured value should not exceed 10 % of these values.

Salinity in the water sources to shrimp farms is affected by seasonal changes. During the wet season, river discharge increases and salinity declines. Conversely, river discharges decrease during the dry season and salinity increases in estuaries. Shrimp ponds are filled with water from canals which receive their flow from the rivers. These are common conditions of shrimp farming in Samut Sakhon and elsewhere and are overcome by management of the time for the grow-out.

The PL of many Penaeid species can tolerate a wide range of salinity fluctuation with little effect to their survival or growth. In grow-out pond conditions, *P. monodon* can tolerate a wide range of salinity from as low as 5 ppt to a high of 40 ppt (NACA, 1986a,b). The salinity at SS2 was the lowest at 10.3 ± 9 ppt and the highest salinity was recorded at SS4 at 27.7 ± 9 ppt.

The value measured at SS2 indicated the nature of this inland operations i.e. an intensive low-salinity freshwater operations. This farm was stocked from a freshwater source and supplemented by hyper saline waster (200 ppt) purchased from salt pan operations. The SS2 operating salinity represents a significant deviation from industry standards. The reason for this change in operating practice is discussed in a later section of this chapter.

The term "pH" refers to the hydrogen ion concentration in water; and refers to how acidic or basic water is. There are few data on the effect of pH on shrimp, and Boyd (1989) has recommended that shrimp respond to pH in much the same way as fish. He suggests that a pH of 4 is the 'acid death point' and the best range for growth is 6 to 9 with 11 representing the 'alkaline death point'. The pH values that range from 4-6 and 9-11 are slow growth ranges. Brackish waters are well buffered against pH change, and pH will seldom fall below 6.5 or rise above 9. Therefore, it is uncommon to find situations where shrimp have been adversely effected by pH (Boyd, 1989).

The pH level suitable for shrimp aquaculture has been suggested to be between the range 8.0 to 8.5 and the Thai coastal aquaculture standard is 7.0 to 8.5. All of the recorded

pH values fell within the recommended Thai standards and range for best growth suggested by Boyd (1989). Only SS5 had a value outside of the suitable range at 7.8 ± 1 .

An important chemical characteristic of water is the level of oxygen saturation throughout the water column. DO is important for shrimp respiration, respiration of the planktonic organisms and for the microbial breakdown of organic matter. The solubility of oxygen is dependent on temperature and salinity. Fluctuations in dissolved oxygen level are closely monitored by shrimp farmers and the oxygen level is preferably not lower than 4 mg/L (Thai standard) and ideally should be greater than 5 mg/L (most suitable). At 4 mg/L the shrimp show signs of stress (i.e. not eating); below 0.7 mg/L they usually die (Napeetapat and Kabilrum, 1987). DO level is regulated (increased) by using aerators and paddle wheels in the shrimp culture ponds.

The lowest values measured for DO were at the mouth of the Thachin (SS5) 3.8 ± 3.4 mg/L and the Pitthayalongkorn canal (SS1) at 4.1 ± 1.7 mg/L. The SS1 canal connects to the Thachin (SS5) several kilometers distant. The highest DO detected was in the intensive shrimp pond at 7.6 ± 4.4 and 8.1 ± 3.9 mg/L respectively. This was expected as the intensive shrimp farm utilizes mechanical aeration to increase the DO content of the water column.

5.3 Results of inorganic constituent analyses

Table 5.2 presents the results of inorganic constituents sampled in the province of Samut Sakhon from five field sampling stations during the period 07 December 1994 to 05 April 1995.

Table 5.2 Inorganic constituents results (mean and range) for 5 sampling stations visited from 07 December 1994 to 05 April 1995 in the province of Samut Sakhon, Thailand.

Variable*	One (n=8)	Two (n=8)	Three (n=8)	Four (n=6)	Five (n=7)
Nitrate	0.1898±0.359	0.223±0.6465	0.1953±0.336	0.0724±0.0934	0.2295±0.1727
Nitrite	0.067±0.1259	0.2288±0.8418	0.0789±0.4249	0.0219±0.0469	0.1876±0.1612
Ammonia	0.256±1.07	0.2728±0.5702	0.1375±0.182	0.0571±0.1127	0.6807±3.4294
Ortho-phosphate	0.1925±0.1872	0.3711±0.7251	0.1381±0.1686	0.1991±0.3266	0.3814±0.5093
TSS (g/L)	0.467±0.29	0.298±0.332	0.664±1.38	0.4113±0.474	0.3403±0.474
Chl a	16.93±44.03	113.72±278.46	18.9±61.88	20.92±34.51	11.56±25.29

Notes: * all units in mg/L except TSS (g/L)

1. Main data and results found in Appendix D and E respectively.

2. Description of Sample Stations: One (canal); Two (intensive pond); Three (canal); Four (extensive pond); Five (Thachin river).

Nitrate is the final product of nitrification and is a major phytoplankton nutrient in marine environments. It is the least toxic of the inorganic compounds. Shrimp can grow normally even at concentrations of 300 mg/L. In a study by Kanit et al. (1992) nitrate levels in a pond stocked at 64 pieces/m² did not exceed 0.13 mg/L.

The highest nitrate levels in this research were recorded at SS5 and SS2 at 0.2295±0.1727 mg/L and 0.223±0.6465 mg/L respectively. The lowest values were recorded at SS4 and SS1 at 0.0724±0.0934 mg/L and 0.1898±0.359 mg/L respectively (Table 5.3). The high values measured in the intensive shrimp pond compares favorably to values measured in other intensive operations. Clearly, intensive shrimp farms operate at elevated nutrient levels in an artificial environment. The high nitrate measured in the Thachin compares to previously recorded values of 0.21 to 1.32 mg/L recorded by Somsiri et al., 1990 (Appendix B-Table B.6).

Nitrate is an intermediate product in the nitrification of ammonia to nitrate. It is toxic to shrimp at concentrations higher than 1.0 mg/L and therefore, is important for aquaculturists. The level considered suitable for shrimp is 0.25 mg/L. (A portion of the nitrite nitrogen in the rearing pond comes from the oxidation of ammonia by bacteria such as *Nitrosomonas*) (Appendix A-Table A.5).

The highest level recorded was at the intensive shrimp pond (SS2) and was 0.2299±0.8418 mg/L. The lowest value recorded during the field study was at the extensive shrimp pond (SS4) at 0.0219±0.0469 mg/L. Shrimp farmers avoid high nitrate

levels through water exchange. The levels in the intensive shrimp pond were higher than all other sample stations.

Ammonia is an important nutrient for phytoplankton and it is excreted by aquatic animals as the major end-product of protein catabolism. The ammonia in a shrimp pond is derived from the decomposition of the organic matter (i.e. left over feed, dead plankton) and from shrimp excretions. The ammoniacal nitrogen content can be divided into unionized ammonia (NH_3) and ionized ammonia (NH_4), the latter being non-toxic ion due to its inability to penetrate through the membrane of a shrimp. However, unionized ammonia can be toxic to aquatic species and is therefore of considerable aquacultural significance.

The temperature of the water, pH and pressure affect the ammonia content (i.e. ammoniacal nitrogen increases when pH increases). The unionized ammonia should not be more than 0.1 mg/L (Appendix A-Table A.5) and levels greater than 0.1 mg/L decrease the growth rate of shrimp with levels from 0.4 to 2.0 mg/L being acutely toxic.

The highest level recorded during the field study was in the Thachin (SS5) at 0.6807 ± 3.4294 and the lowest level was recorded at the extensive shrimp farm (SS4) at 0.0571 ± 0.1127 mg/L. All of the values with the exception of SS4 were above the recommended level suitable for shrimp. and the value at in the Thachin river at an acutely toxic level (very high on occasion as the range indicates). Notably the value at the intensive farm was above the recommended level.

The phosphorus concentration in the water is closely correlated with the primary productivity of most waters and is important for the growth of phytoplankton. Phytoplankton are able to utilize orthophosphate which has a solubility of less than 0.1 mg/L in saline water. Most of the orthophosphate is precipitated and absorbed between the clay particles at the pond bottom of shrimp ponds. The concentration of usable phosphate for phytoplankton depends upon the decomposition rate of organic matter in the water, precipitation and the photosynthetic rate of phytoplankton.

The highest level of orthophosphate was recorded at the Thachin river at 0.3814 ± 0.5093 mg/L. The value in the intensive shrimp pond was 0.3711 ± 0.7251 mg/L. The lowest level was recorded in the small canal (SS3) at 0.1381 ± 0.1686 . Once again the canal

water and the extensive farm operation are closely analogous while the intensive farm operates at an elevated nutrient level.

The highest level of TSS (g/L) was recorded at the large canal (SS1) at 0.467 ± 0.29 g/L (i.e. highest turbidity) and the lowest value was recorded at the intensive shrimp pond at 0.298 ± 0.332 g/L (i.e. lowest turbidity). The turbidity levels are also reflected in the lowered Secchi disk values at these stations.

There are no established suitable levels, however, the recorded levels in this field study are within the ranges reported for intensive shrimp farms in southern Thailand (Appendix B -Table B.2). A characteristic of the Upper Gulf water sources (canals and rivers) is the high turbidity.

Chlorophyll *a* is a plant pigment, the concentration of which is an index of phytoplankton levels. The content of chlorophyll *a* in the shrimp rearing ponds is related to the nutrient concentration in water and is dependent upon the stocking density, feeding quantity and water exchange.

The highest value of Chl *a* was recorded at the intensive shrimp pond 113.72 ± 278.46 mg/L and the lowest value recorded was in the Thachin river at 11.56 ± 25.29 mg/L.

The recorded levels for physical and chemical parameters and inorganic constituents indicate the difference between the intensive and extensive systems. The intensive shrimp farm operates in an artificial environment with elevated nutrient levels. Prevention of negative or elevated water quality conditions is actively undertaken by the intensive shrimp farmer through chemical inputs, water exchange or aeration. All of the water quality parameters are altered to maintain desired levels. In contrast, the data from the extensive pond clearly indicated lower values than the intensive system. The improved water quality can be attributed to the fact that there are no feed inputs, or very little, no chemicals other than pond preparation applications, no aeration and water exchange occurs through tidal exchange.

5.4 Results of phytoplankton counts

Bi-weekly phytoplankton samples were taken during a period of 6 months, from December 1994 to April 1995 at three sampling stations in Samut Sakhon. Sample Station One was a large canal (i.e. Pitthayalongkorn), Sample Station Three was a small canal (i.e. Promdan) and Sample Station 5 was at the mouth of the Thachin River. All three of these water sources supply shrimp farms. At each of these stations physical and chemical and inorganic constituent information were also collected (see results above). Table 5.3 presents a summary of the number of plankton species by phylum found at the sample stations. Refer to Appendix C for a complete presentation of the plankton data. Although beyond the scope of the thesis, a more thorough analysis of plankton is suggested for the intensive and extensive shrimp pond environments. The results this work indicate the potential value of doing such an analysis.

Table 5.3 Summary of the number of plankton species by phylum found at the sample stations

Phylum (common name)	SS1-canal	SS3-canal	SS5-river
Chlorophyta (green algae)	0	0	0
Cyanophyta (blue green)	1	1	1
Bacillariophyta (diatoms)	17	12	12
Pyrrophyta (dinoflagellates)	4	4	4
Protozoa	1	3	1
Arthropoda	0	1	2
Total	23	21	20

Few reports examine the specific phytoplankton species associated with intensive shrimp farming. However, the species composition in shrimp ponds are important because the different taxa of planktonic algae present a range of dietary values. In general, the phytoplankton species occurring in shrimp and fish operations include members of **chlorophyta** (green algae), **cyanophyta** (blue-green algae), **bacillariophyta** (diatoms), **euglenophyta** (euglenoids), and **pyrohophyta** (dinoflagellates). Data from the plankton enumeration's was classified into these categories. The necessary information for shrimp farm operations might include knowing: the desirable phytoplankton species compositions, biomass and productivity for sustaining optimal yield of the crop; the phytoplankton response to fertilization (organic and inorganic); and the nutrient assimilative capacity of a particular phytoplankton community.

The species of plankton occurring at the field sampling stations varied on the different sampling dates. Many explanations have been given for changes in the total abundance of phytoplankton in a body of water (Fogg, 1965). Possible causes of the fluctuations include changes in pH temperature, light intensity and nutrient concentrations, grazing by zooplankton or fish, diseases, parasites, and release of algal toxins by other organisms. Seasonal effects may explain some of the above, however, none of the explanations is sufficiently general to be of use in shrimp pond management. Decreasing salinity during the wet season often causes phytoplankton communities to shift from diatoms to green or even blue green algae and with respect to shrimp culture, diatoms are considered a better food than other types of algae (Boyd, 1992).

It is difficult to discern the effects of natural changes in the aquatic environment. The sample populations are susceptible to natural changes in the aquatic environment making observations related to shrimp farming difficult. Table 5.4 presents the most commonly observed species of plankton at the three sampling stations. No green algae were detected. Some of the diatoms were present in large numbers on several occasions (Appendix C).

Table 5.4 Most commonly observed species of plankton at each of the sampling stations. For cells/L see Appendix C.

Pitthayalongkorn Canal (SS1)	
Common Name	
Blue green	<i>Oscillatoria</i>
Diatoms	<i>Biddulphia, Coscinodiscus, Nitzschia, Skeletonema</i>
Dinoflagellates	<i>Noctiluca</i>
Protozoa	<i>Tintinnopsis</i>
Arthropoda	<i>Copepod</i>
Canal Promdan (SS3)	
Blue green	<i>Oscillatoria</i>
Diatoms	<i>Coscinodiscus, Nitzschia, Pleurosigma</i>
Dinoflagellates	<i>Noctiluca</i>
Protozoa	<i>Tintinnopsis</i>
Arthropoda	<i>Copepod</i>
Mouth of the Thachin River (SS5)	
Blue green	<i>Oscillatoria</i>
Diatoms	<i>Pleurosigma, Nitzschia, Skeletonema</i>
Dinoflagellates	<i>Ceratium</i>
Protozoa	<i>Tintinnopsis</i>
Arthropoda	<i>Copepod</i>
Rotifera**	<i>Rotifers</i>

Notes: 1. No green algae were detected at any of the sampling stations.
2. Rotifers were only detected at SS5.

The implications of an over-abundance of plankton in the culture ponds are pond shading, the consumption of oxygen, and excretion of harmful metabolites. If the plankton reach sufficient quantities there are concerns for the shrimp farmer. Hypernutrification and eutrophication are discussed below. The phytoplankton bloom is therefore carefully monitored. Information regarding the suitable species of plankton is lacking. Some information on the diatom *Nitzschia* is relevant to shrimp farmers in the Upper Gulf region. All of the sample stations had *Nitzschia* in large numbers. *Nitzschia* attaches to the gill filaments of shrimp creating a negative synergistic effect to the respiratory mechanisms of shrimp when in combination with poor water quality. The observed solutions to this problem implemented by shrimp farmers in Samut Sakhon involved increasing the storage capacity for water and improving the technical aspects of farm management.

Correlation of abundance of the plankton with nitrate, silicate, phosphate and other inorganic contaminants was made. No correlation for DO, salinity, and pH was undertaken. Previous work in Thailand examining phytoplankton abundance and its relation to water quality and shrimp production has been conducted for shrimp farms in the province of Nakhon Si Thammarat by Pongmaneerat et al. 1985. Though plankton information is site specific, the results of some plankton enumeration's in Southern Thailand are included for comparison (Appendix B Table B.12).

The shrimp pond environment is artificially maintained to suppress the conditions of hypernutrification and eutrophication. Within the shrimp pond this is accomplished by continuous aeration and water exchange to maintain optimum growing conditions for the shrimp crop. Based on the nutrient levels of the intensive shrimp pond effluent, eutrophication or hypernutrification may be increased in the receiving environment external to the shrimp farm.

Nutrient enrichment (usually by nitrates and phosphates) in aquatic ecosystems if unchecked can result in eutrophication in which the productivity of the system ceases to be limited by the availability of nutrients. This process of eutrophication can occur naturally over geological time but is often accelerated by human activities (e.g. agricultural fertilizer runoff, waste disposal by manufacturing processes or the draining of domestic sewage). Such impacts are referred to as 'cultural eutrophication'. The rapid increase in nutrients in areas of limited flushing stimulates algal blooms. On death,

bacterial decomposition of the excess algae may deplete oxygen levels seriously leading to the death of fish and shrimp.

High density coastal shrimp farming can lead to the overloading of coastal areas, where it can lead to hypereutrophication. Research conducted on this condition in the coastal areas of Songkhla province, Thailand and reported in that 77.5 % of N and 86 % of P added to shrimp ponds is lost to the environment (Macintosh and Phillips, 1992 and reported in OEPP, 1994a) and may lead to changes in the receiving waters. This increase in nitrogen and sedimentary carbon may cause benthic enrichment followed by changes in species composition and abundance. The subsequent reduction in macro fauna biomass and the growth of sulfur bacteria are signs of this type of benthic overloading (Rosenthal, 1994). This overloading then results in excessive nutrient release, which usually leads to 'hypereutrophication' and oxygen depletion in areas of limited water exchange and with subsequent effects on the farm itself.

The build up of dissolved organic matter from metabolites and decomposition of uneaten food and shrimp faeces and subsequent discharge to the sea from intensive shrimp farming operations may cause considerable harm to the coastal marine environment (Quarto, 1992). It has killed coral reefs and created toxic algal blooms offshore (Stanley, 1993) and resulted in fish death and foul-smelling water in many wetland areas (Masae and Rakkheaw, 1992). An excellent example of overloading by aquaculture systems was the uncontrolled development of fish pen culture in Laguna de Bay, near Manila in the Philippines. The ecosystem carrying capacity was vastly exceeded leading to a steep decline in the quality of the culture grounds. In British Columbia, coastal aquaculture expansion is a critical management concern.

Reports for Thailand have stated that shrimp farming increases the risk of hypereutrophication and eutrophication, with increased primary productivity and higher probability of phytoplankton blooms, decreased oxygen and increased concentrations of micro-organisms (OEPP, 1994a). The current industry position maintains that since there are no studies that can make a direct connection between intensive shrimp farming and the incidence of eutrophication and hypereutrophication no change in practice is warranted (See however the precautionary principle this chapter).

5.5 Results of organic contaminant analyses

Table 5.5 presents the organic contaminants (pesticides) detected by field sample investigation from five stations in the province of Samut Sakhon on two occasions (07 December 1994 and 09 March 1995).

Table 5.5 Organic contaminants (pesticides) detected by field investigation from various locations in the province of Samut Sakhon, Thailand from December 1994 to March 1995

07 December 1994		09 March 1995	
Station One: Pitthayalongkorn Canal-Large Canal in Amphoe Muang			
	Level (ng/L)		Level (ng/L)
Heptachlor	ND	Heptachlor	11.5
Dieldrin	5.7	Dieldrin	ND
DDE	2.1	DDE	ND
DDD	1.4	DDD	23.7
Total DDT	3.5	Total DDT	23.7
Station Two: Intensive Shrimp pond "low salinity" in Amphoe Ban Phaeo			
Heptachlor	23.8	Heptachlor	0.03
Dieldrin	4.4	Dieldrin	ND
DDE	1.5	DDE	ND
Total DDT	1.5	Total DDT	ND
Station Three: Canal Promdan -Small Canal in Amphoe Muang Tambol Nakho			
Heptachlor	ND	Heptachlor	20.2
Dieldrin	5.7	Dieldrin	ND
DDD	2.6	DDD	29.7
Total DDT	2.6	Total DDT	29.7
Station Four (Extensive shrimp pond in Amphoe Muang Tambol Nakho)			
Heptachlor	ND	Heptachlor	1.8
Dieldrin	5.9	Dieldrin	ND
DDE	1.9	DDE	ND
DDD	5.1	DDD	6.3
Total DDT	7.1	Total DDT	6.3
Station Five: Mouth of the Thachin River in Amphoe Muang Tambol Bangyapet			
Note 1.	-	Heptachlor	4.3

Notes: 1. No sample was collected from Station 5 in December 1994.

2. Results based on the collection of two field samples.

3. Total DDT is the addition of its derivatives DDD and DDE.

4. ND = Not detected

Persistent organic pollutants have a number of general effects. Cooper (1993) reviewed the biological effects of surface water pollutants from agriculture on aquatic systems. Many pesticides particularly insecticides (i.e. polychlorinated biphenyl's, organochlorines, organophosphates, and carbamates), are extremely toxic to fish and shrimp, generally in the parts per billion (ppb) concentrations. Toxicity levels of some pesticides to penaeid shrimp are shown in Appendix-Table A.9 (See Couch 1978 and

Couch 1979 for further discussion). Sub-lethal effects on reproduction could be anticipated at levels well below these actual toxicity levels (Fast and Lester, 1992). Acute toxicity values for several commonly used insecticides range from 5 to 100 mg/L (Cope, 1964). Although they may not cause mortality they may decrease the growth of food organisms and thus decrease growth and productivity. In addition, they may reduce reproduction processes or reduce the viability of offspring (i.e. they also have sub-lethal effects). As shrimp are closely related biologically to insects they are particularly vulnerable to pesticides throughout their life cycle.

Despite what is known about organic contaminants, especially the persistence of organochlorine pesticides, their use in Thailand has increased in conjunction with the development of high-yielding rice varieties. The quantity of pesticides applied in the central region, the highest in the country, accounted for 62 % of the country's total in 1988 (ADB, 1989). Uttarapong and Tientong (1993) analyzed 54 water samples from 11 stations on the Thachin river for organochlorine pesticide residues. Dieldrin, DDE, Lindane, Aldrin and DDT were found in the range of less than 0.001 to 0.034 $\mu\text{g/L}$ with most of the residues being dieldrin and DDE at the level of 0.002 $\mu\text{g/L}$ and 0.34 $\mu\text{g/L}$ respectively. Heptachlor was detected in 11 fish species in the range of 0.61 to 2.7 $\mu\text{g/kg}$.

In this work the highest levels (ppb) of the detected pesticides heptachlor, DDE, dieldrin and DDD were 23.8, 1.9, 5.9 and 29.7 ng/L respectively. The levels of dieldrin, DDT and heptachlor exceeded the recommended safe levels for pesticides in water suggested by various authors (Appendix A-Table A.8). All of the pesticides detected in the field study are non-registered for use in Thailand (Appendix A-Table A.10). None of the detected organics exceeded any of the suggested toxicity values (Appendix A-Table A.9).

The levels of organic contaminants detected in the intensive and extensive shrimp ponds showed similar or higher levels to those detected in the canals. This illustrates that the organic contaminants were ubiquitous. Therefore, the culture ponds for shrimp are not immune to the effects of these agriculturally derived contaminants. The high heptachlor value found at the intensive shrimp pond can be attributed to agricultural activities in this upland region of the province. The DDT in the extensive shrimp pond can be attributed to the high value detected in the Canal Promdan which supplies this pond. The results show that all types of shrimp farms, extensive or intensive, are receiving

contaminants via the water supplies. The type of shrimp farm does not affect the level of pesticides arriving by the water supply. The contaminated water sources of the Upper Gulf shrimp farms is a factor behind the trend of relocating inland or out of region.

Comparison to the established standards can be misleading. All organic contaminants have potentially sub-lethal effects. The early life stages of *P. monodon* are particularly susceptible to organic contaminants. The performance of shrimp farms in the case study region are all influenced by organic contaminants. The application of pesticides for agricultural use is the major contributor of the organic contaminants detected in the field study.

5.6 Results of metal analyses

Table 5.6 presents the heavy metals detected by field sample investigation from five stations in the province of Samut Sakhon on two occasions (07 December 1994 and 09 March 1995).

Table 5.6 Heavy metals found in water samples taken from various Samut Sakhon shrimp farming areas from December 1994 to March 1995

Metal (ppb)	One		Two		Three		Four		Five
	Dec. 1994	Mar 1995	Dec. 1994	Mar 1995	Dec. 1994	Mar 1995	Dec. 1994	Mar 1995	Mar 1995
Zn	4.74	3.62	9.54	2.82	8.61	10.33	4.86	4.92	7.19
Cd	1.85	0.65	1.91	0.53	1.30	0.62	1.37	2.41	0.82
Cu	0.97	3.13	1.71	1.23	2.34	3.80	3.57	1.57	7.08
Pb	0.04	0.08	0.04	0.10	0.17	0.40	0.01	0.24	0.34
Fe	110.17	124.33	24.19	152.97	158.92	134.33	14.41	129.10	172.33

Tables in Appendix B present the heavy metal levels detected in various river estuaries used as water sources for shrimp farms, ground water sources and in the shrimp ponds themselves. Table B.7 presents the levels of heavy metals detected in the main estuaries that drain to the Gulf of Thailand by Anat et al., (1987). A 1993 study conducted by the Samut Sakhon Coastal Aquaculture Development Center indicated the heavy metal

residues by location along the Thachin river. The mouth of the river contained the highest amount of the heavy metal residues.²

Appendix B contains information tables that make comparisons of heavy metal level with recommended safe limits. Appendix A -Table A.6 suggests the toxicity level ranges of 96-hour LC-50's and the safe levels recommended by the USEPA for heavy metals. For similar comparison, the median international standards and ranges in such standards ($\mu\text{g/g}$ wet weight) for trace elements in freshwater and marine fish and shellfish is provided (Nauen 1983).

Collected samples were analyzed for the following: zinc, cadmium, copper, lead and iron. The highest levels detected all occurred on the 09 March 1995 sampling date. Sample Station Three had the highest values for Zn and Pb at 10.33 ppb and 0.40 ppb respectively. Sample Station Four has the highest levels of Cadmium at 2.41 ppb. Sample Station Five had the highest levels of Cu and Fe at 7.08 ppb and 172.33 ppb respectively. The levels of metals detected in the extensive and intensive shrimp pond did not differ significantly. The copper value detected at the extensive shrimp pond can be attributed to the common practice of using copper sulfate on the pond bottoms to eradicate shrimp predators prior to stocking. Cadmium was detected at all of the sampling stations.

None of the values exceeded the toxicity values offered by Boyd (1989). However, the cadmium and lead values exceed the safe level recommended by the USEPA. The Cd level also exceeds the median standard for fish suggested by Nauen (1983). All of the values exceed the suitable levels suggested for shrimp ponds with the exception of Cd (Appendix A-Table A.5). The fact that Cd exceeds the median standard and not the 'suitable' standards suggests that the "suitable" level be increased to include lower concentrations of Cd.

It is noted that the general increase in values for heavy metals from December to March is beyond experimental error (duplicates and standards were used in analysis) and that metal levels in the shrimp farms used for production for human consumption are not markedly different from that of the local canals and rivers.

² In a similar study of the Chao Phraya river Onodera (1985) compared the results to the Thai standards. Also, shrimp farm operations utilize ground water supplies. Table B.11 presents the results of a study by the Ground Water Division during the period 1982 to 1985 which reported the heavy metals detected in ground water in Thailand.

Heavy metals in water sources available to shrimp farming operation may negatively impact shrimp culture operations. Knowledge of the heavy metal burdens and an understanding of the mechanisms for demobilization are becoming increasingly important factors in shrimp farming, especially in areas now subject to industrial developments. Most short-term toxicity tests indicate the requirement to be extremely cautious in siting of reproduction facilities as well as in possible contamination of sea water systems by construction materials. A critical point of impact in aquaculture is reproduction and growth. Specific standards for heavy metals as related to their influence on reproduction, either lethal or sub lethal do not exist (Fast and Lester, 1992). Toxicity comparisons and median international standards are found in Appendix A-Table's A.6 and A.6. The effects of heavy metals on shrimp was subject to a study by Vogt and Quintio (1991) who examined the fate and effects of the water borne heavy metals of cadmium, copper, iron and lead in *Penaeus monodon* and found that severe cellular damages were only induced by cadmium.

5.7 Observations on the intensive shrimp farm cycle in Samut Sakhon

Evidence gathered through field observation in the province of Samut Sakhon suggests that the cycle that has occurred in this province is closely analogous to that being reported globally. The shrimp farm cycle is categorized according to the following phases of operation: Phase I - period of increasing production; (2) Phase II - period of stable production; and Phase III - production declines; and lastly Phase IV - post-production use of land/abandonment state. The observed cycle provides important information for the strategic sustainability assessment in Chapter 6. A conceptual illustration of the shrimp farm cycle described below is shown in Figure 20.³

³ The conceptual illustration of the shrimp farm cycle portrays the loss of 'capacity' of the biophysical environment to support shrimp farming. This situation of biophysical exploitation is analogous to the 'boom and bust' pattern of the North sea herring fisheries and the Baltic cod fisheries.

5.7.1 Phase I - Period of increasing production

Newly commissioned shrimp farms in the Upper Gulf, including Samut Sakhon, in their early stages of operation, generally exhibit a rapid increase in pond productivity and total product output. Shrimp farmers at this early stage are eager to recoup initial investment and therefore stock ponds with increased densities to maximize profits in the short term. Land is modified and cleared of vegetation and new entrant shrimp farming operations concentrate the effort by populating specific areas or regions. The environment, both the local receiving and supply waters, have some measure of capacity to withstand these dramatic changes in the short term. As the farming region matures there is gradual decline in the viability of the receiving environment which is temporarily compensated by increased chemical treatments to both the water and pond soils. This phase of farm operation reaches a plateau of stable production as the capacity for new entrants is achieved and locally farms are managed to overcome biophysical constraints. At a regional level operation this period lasted for approximately one year. The duration of this phase will be slightly longer for farms with more sophisticated management techniques.

5.7.2 Phase II - Period of stable production

Shrimp farming operations in the province of Samut Sakhon that passed through the one year mark were able to recoup initial investments in just 1 to 2 crops. At this point they were producing crops at the maximum output. Achieving this level of output was in most cases at the expense of the support systems of the surrounding environment, especially water systems. Some of the well managed farms were able to avoid the onset of negative feedback allowing operation at this level of production for a period of one to two years.⁴ . Negative externalities of the farm (i.e. over intensification, location crowding, diminishing source water quality; and decreasing pond bottom soil productivity) eventually leads to decline. Other provinces of the Upper Gulf experienced similar declines, though in some cases not as dramatic as that which occurred in Samut Sakhon.

⁴ Negative feedback in shrimp culture is the damaging effect of using stocking water from canals that have been contaminated by discharge from the same or nearby farms.

5.7.3 Phase III - production declines

As experienced in many other locations the shrimp farms in Samut Sakhon experienced production declines at the 6 to 8 crop mark (i.e. near the third year of operation when 3 crops per year were cultured, some as early as the second crop). The productivity collapse in this province was characterized by region-wide failure of shrimp farms. Production declines are usually linked to massive outbreaks of disease. The immediate response was abandonment of the ponds. Such self-pollution, increased the shrimp farm risk to disease. The situation provided the opportunity for pathogens that were always present to increase beyond their normal numbers. The presence of these pathogens under 'normal' circumstances would not have created a problem for the shrimp farmers. As the effectiveness of the chemical treatments decreased the incidence of crop failure further increased.

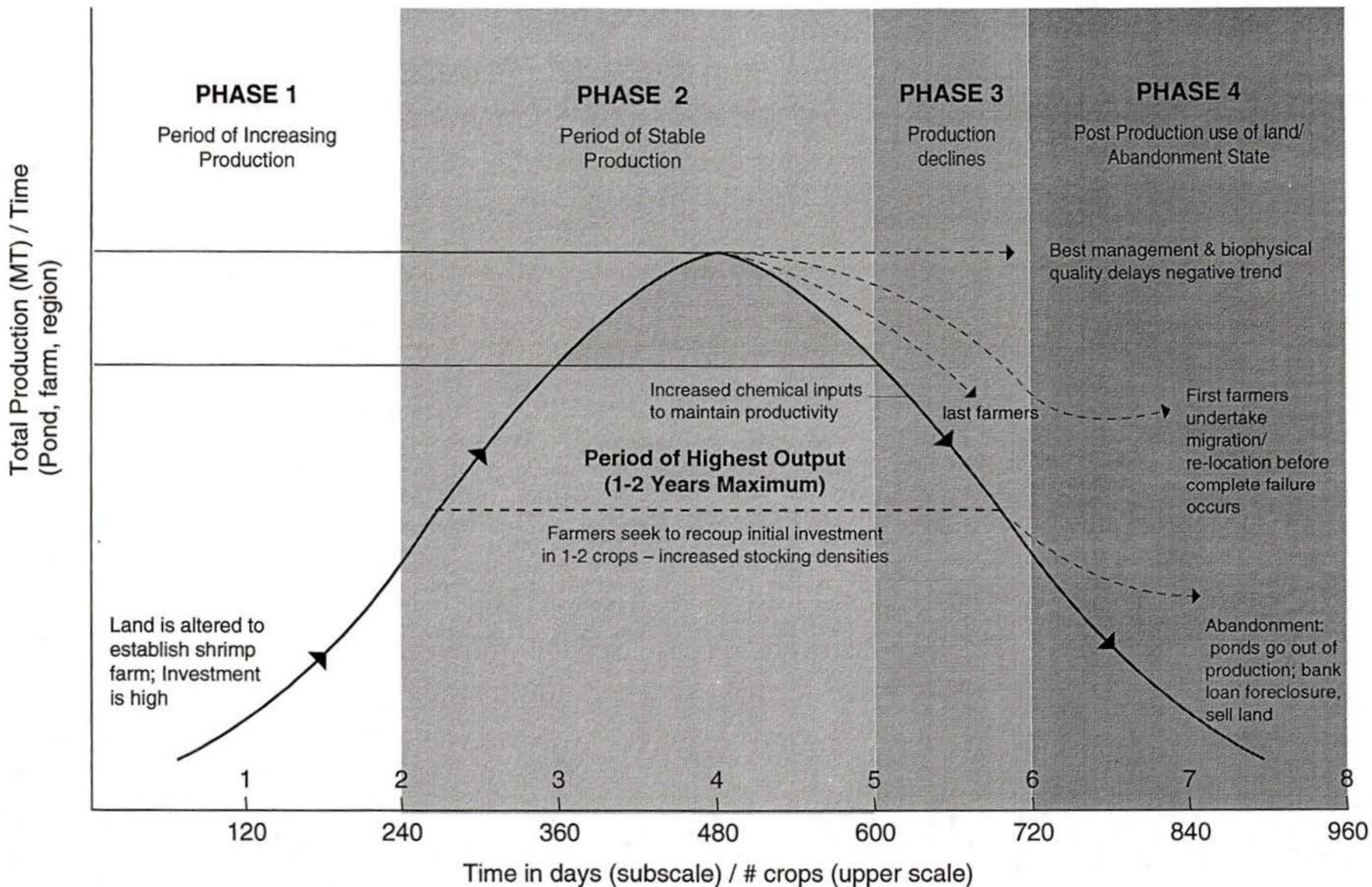
5.7.4 Phase IV - Post production use of land/abandonment state

At this phase of the shrimp farm cycle opportunistic shrimp operators with substantial capital resources directly vacated their farms for more suitable culture areas. Choices available to the farmer were dependent upon economic constraints. There was little economic imperative to continue operations as initial investments had long since been returned. Some shrimp farmers, generally small-scale operators, remained until complete region-wide collapse occurred. This failure of these culture operations led to loss of income, loss of land and bank foreclosures on loans. Conversion for these small operators to new uses is restricted by the insufficient financial resources and the damaged and degraded state of the land.⁵ Figure's 21 and 22 provide several images of what is referred to as the 'abandonment state'.

The following sections will elaborate both the general and specific causes for the productivity declines. General causes are related primarily to the industry as a whole while specific causes are those observed during the field investigation in Samut Sakhon. No one cause leads to productivity collapse. A combination of contributing factors is nearly always involved.

⁵ A reminder to the reader that the majority of aquaculture farming operations are small-scale in nature. These holdings make up 80 % of the number of culture operations in most regions of Thailand including Samut Sakhon province.

FIGURE 20. CONCEPTUAL ILLUSTRATION OF THE SHRIMP FARM CYCLE



Assumptions: 1 crop cultivated every 120 days. Period between farm cycles dependent upon individual farm methods for returning pond into production generally 30 days.



FIGURE 21. ABANDONED SHRIMP FARM IN AMPHOE MUANG, SAMUT SAKHON NOW BEING USED AS A REFUSE DUMP

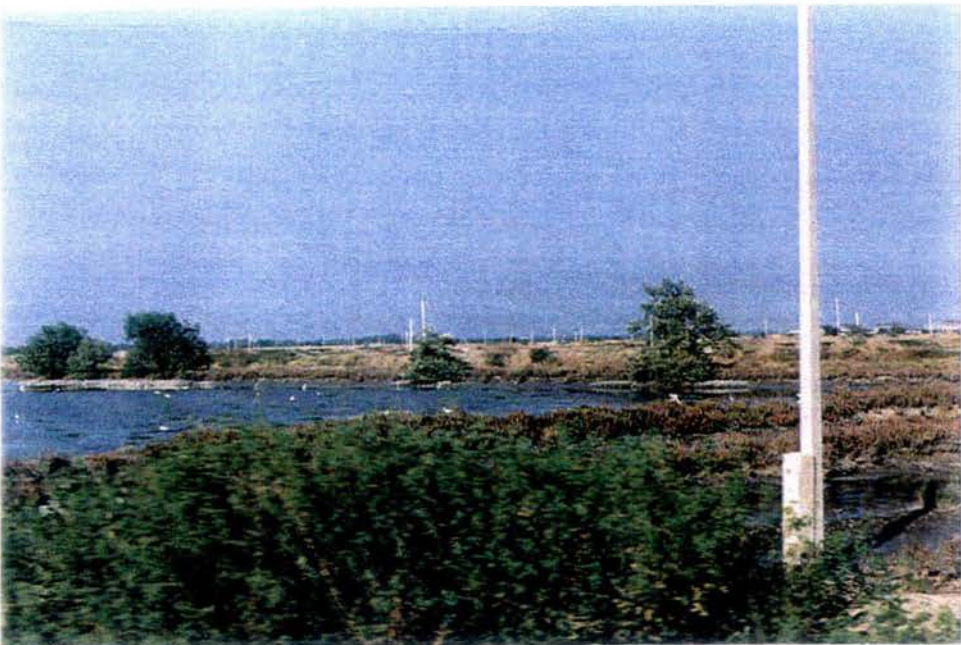


FIGURE 22. UNDEVELOPED ABANDONED SHRIMP FARMING AREA IN SAMUT SAKHON

5.8 Observed causes for failure of Samut Sakhon shrimp farming cycles

A number of inherent flaws in the shrimp farming cycle were observed in this research (Table 5.7). These flaws are common to all intensive operations, globally and in Thailand. As a result, a discussion of productivity declines in the regional case study (Samut Sakhon province) can be related to other regions of the Upper Gulf, and provide a basis for preventative (precautionary) action in other areas. The following section reports the present researcher's experience and knowledge gathered during field investigation of failures in the province of Samut Sakhon.

Table 5.7 Causes for failure of shrimp farming cycles in the province of Samut Sakhon

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- Mass mis-application of shrimp farming technology
 - Over intensification leading to ecosystem overloading
 - Poorly engineered and inadequately constructed farming systems
 - Lack of site specific regulations for shrimp farming regions combined with weak enforcement of regulatory standards
 - Excessive stocking densities and pond mismanagement
 - Get rich quick attitude among entrepreneurs
 - Lack of regulation of the use of chemicals
 - Failure to utilize ecologically sound production systems
 - Lack of research on pond dynamics
 - Levels of other human activities in the Upper Gulf of Thailand
 - Site specific factors for Samut Sakhon- biophysical limitations

5.8.1 Mass mis-application of shrimp farming technology

The rapid global expansion of intensive coastal aquaculture has been fueled by importation and transfer of "off the shelf" culture practices and readily available technology. There have been both good and bad consequences for the industry. Importing shrimp farming technologies from other jurisdictions, has distributed both success and failure throughout Asia.⁶

⁶ The early groundwork for industry development and expansion in Thailand began when Thai scientists adopted successful Japanese hatchery techniques that allowed for the commencement of aquaculture at a new and larger scale. Improved feed processing technologies allowed for both the increase in feed supply and quality.

Thai operations have been established through the import of information, materials and capital from apparently well qualified and experienced Taiwanese shrimp farming companies. These transfers occurred despite prior knowledge of the pathogenic and non-pathogenic factors contributing to the crash of the shrimp aquaculture industry in Taiwan during the period 1987 to 1989 using this same technology. Reports had identified in detail the causes behind the crash (Lin, 1989). Although the lessons learned were publicized almost immediately, the mistakes committed in Taiwan were replicated in Thailand and many other countries of the region. Following the crash, Taiwanese investors made large investments of money for the transfer and development of intensive aquaculture to the provinces of the Upper Gulf of Thailand. The methods utilized in Taiwan were directly imported into Thailand and resulted in the replication of the 'pattern of failure' without making the necessary fundamental changes to improve the sustainability of shrimp farming practices.⁷

This 'pattern' appears to be repeating once again as experienced Thai shrimp farmers and investors, some emerging from the Upper Gulf experience, are interested in pursuing shrimp farming operations abroad. The repeated use of the techniques that destroyed the industry in Taiwan and the Upper Gulf of Thailand are beginning to shake the industry in southern Thailand, Indonesia and the Philippines, and still further expansion is imminent both within Thailand and in other countries. The latter now look to Thailand for advice and information concerning shrimp farming. For example, Thailand has already made several trade missions to Mexico to establish strategies to transfer the current industry practices. Disturbingly, there are no indications that fundamental corrections of past mistakes will be made prior to implementation in these 'frontier' shrimp farming countries. Therefore, it will not be surprising to learn of other examples of this phenomena before the entire industry is made to deal with the problems resulting from shrimp farming practices.⁸

⁷ It may be argued that these investors were fully cognizant of the required changes to increase sustainability of operations but chose to ignore them based on the quick and lucrative profits available. Thus, the industry expansion occurred without precaution for the environmental impacts that may result.

⁸ A report by the FAO Fisheries Department entitled, The State of the World Fisheries and Aquaculture in 1995 found that due to the widening of the gap between the average salary of people in Africa and those in Asia entrepreneurs will find it increasingly commercially attractive to develop aquaculture production units in Africa. These would of course utilize the favorable physical environment, cheaper African labor with Asian capital and technology.

5.8.2 Over intensification leading to ecosystem overloading

Over intensification of operations often exceeds the assimilative capacity of the supporting and receiving ecosystems. Rapid expansion of aquaculture with concentration in one particular area, combined with overall poor water management creates the overloading of the external macro-ecosystem. Farms operating in this manner then experience a severe decline of the internal micro-ecosystem as farmers intensify production and neglect the limits of resource and individual pond ecosystem sustainability. Several examples from the author's experience in Thailand illustrate this scenario as follows.

The early traditional trapping-growing aquaculture ponds, converted from salt farms and rice paddies, were primarily located in Samut Sakhon and other provinces of the Upper Gulf. In 1981, 88% of the total shrimp pond area in Thailand was located in these provinces. Although there was a concentration of shrimp farming activity in these early years it was the increasing numbers of intensive farms that would lead to the onset of environmental problems. The difference between these situations can best be illustrated by using an indicator for 'production density' (others include 'culture area density' and 'farm density' and will be discussed further in Chapter 6). For example, in 1989, there were 356.16 MT of shrimp produced per kilometer of coastline in Samut Sakhon compared to 76.80 MT in 1991 (See discussion by Csavas, 1994a). Evidence of this level of intensification has been reported by (Briggs and Funge-Smith (1994) wherein they describe the high concentration of farms on the mouths of rivers and canals in the polluted Upper Gulf region. They claim that the high profits "encouraged the rapid proliferation of the industry until it occupied almost all of a strip of land stretching from the shoreline to up to 4 km inland for more than one hundred kilometers". This description of the extent of shrimp farm development in the Upper Gulf in the industrial heartland of Thailand which led to ecosystem overloading and stressing of the macro-ecosystem (coastal environment). To sustain the high production levels achieved in the Upper Gulf the intensive shrimp farms required a high degree of ecosystem appropriation on a regional basis.

5.8.3 Poorly engineered and inadequately constructed farming systems

There are well established criteria and techniques to assist in the selection of intensive aquaculture sites (Chiu, 1988; Poernomo, 1990). Upper Gulf shrimp farms commissioned in the late 1980's could not meet the basic primary requirements of adequate water supply and discharge systems.⁹ Overlooking this critical factor reflects the lack of planning and short-term mentality of the early shrimp farmers.¹⁰ In Samut Sakhon it was common to have both inadequate water supply, and drainage canals for effluent discharge. Often the same systems were utilized for both operations. This situation created very restricted pumping arrangements for water exchange in an area of poor tidal flushing. Water exchange requirements for these poorly engineered intensive systems in the Upper Gulf exceeded the flow rates of the tidal supply. The net result was a condition referred to as 'self-pollution' where instead of replacing waste with clean water, the farms were very often recycling waste water.¹¹ Numerous poorly designed farms could be seen abandoned when enroute to the field sampling stations in Samut Sakhon.

Developers responsible for the construction and commissioning of shrimp farms have little or no understanding of the site hydrology and soil characteristics, especially of those sites prone to acid sulfate conditions.¹² Well-informed farmers often chose to ignore site selection criteria in the face of quick fortune. The rapidity of construction and expansion of shrimp farming in Samut Sakhon meant that no standard construction methods were adhered to that would protect or safeguard the farm from any deterioration of its environmental conditions. These farms were congenitally predisposed to negative environmental factors by their initial construction and siting.

⁹ For an excellent reference regarding design and operation of sea water aquaculture systems see Huguenin and Holt (1989).

¹⁰ The poor site selection and overall engineering of farming systems shows the consequence of the lack of environmental impact assessment in the shrimp farming industry in Thailand.

¹¹ For further information regarding aquaculture 'self-pollution' see papers by Barg (1992) and Chamberlain (1991).

¹² This condition would be particularly severe for sites constructed on what was previously mangrove.

5.8.4 Lack of site-specific regulations for shrimp farming regions

In Thailand, there are no 'site'- or 'region'-specific regulations for management practices in spite of the varying physiographical conditions of the coastal lands and waters where farms are located. In the case of Samut Sakhon, the restrictive hydrographic conditions of the Upper Gulf region necessitate a very different set of conditions than those required for farms located in southern and eastern Thailand. If regional limitations to shrimp farming had been based on specific regulations matched to the local biophysical constraints the severity of productivity collapses would have been minimized. This seems to be a necessary consideration for the establishing of future developments and to guide the operation of existing shrimp farms in such regions. Efforts toward achieving such regulations are discussed in the recommendations for solutions in Chapter 6. Personal observations of the Samut Sakhon operations clearly demonstrated the need for such a regulatory approach.

5.8.5 Excessive stocking densities and pond mismanagement

Shrimp farmers utilize pond stocking densities that exceed the capabilities of both the pond and external environment. The Amphur Ban Phaeo farm (field sampling Station 2 this work) used stocking densities that ranged from 52 to 94 PL per meter squared. These densities are levels far above the 'suitable' level recommended for intensive operations (30 PL per meter squared). In Taiwan pond carrying capacities were also exceeded by excessive stocking densities to the point where the problems created by this management practice were irreversible.

Although crops were successfully cultured from this initial stocking density the biophysical resources required this level of production far exceed the capabilities of the surrounding support ecosystems. As in most farms of the region, this practice would not be sustainable in the long-term. For example, the mortalities that reached epidemic proportions in Taiwan from 1987 to 1989 and in Thailand's Upper Gulf industry from 1989 to 1991 were not caused by introduced new diseases, as initially suspected, but rather by local, opportunistic pathogens present in practically all coastal waters. Csavas (1992) has suggested that these pathogens do not cause excessive disease outbreaks without mis-management of the pond ecosystem.

5.8.6 Inexperience, lack of dedication and attitude of shrimp farming entrepreneurs

In most new industry developments the early participants have not had the benefits of previous experience to assist them. The 'pioneers' in the intensive shrimp farming industry fall into such a category. When the industry developed in the Upper Gulf many of the new entrepreneurs had no expertise and were not dedicated to responsible shrimp farming in the long term. The early industry in the Upper Gulf was lead by a 'profit driven' and 'too-good-to-miss' mentality that was not surprising, since initial investment could be recouped in just one or two crops. The scene was reminiscent of a "gold rush".

Huge returns on investment in Taiwan encouraged Thai businessmen to enter this field. After 1987, many intensive shrimp ponds were developed, often without the necessary technical background in shrimp culture (Kikuchi, 1993). New entrants to the shrimp culture industry were: (1) farmers originally residing in this area who converted some of their own land into intensive shrimp ponds from rice culture, salt farming and other agricultural related activities; (2) farmers who had suitable land for shrimp culture but didn't have the capital to set up the ponds, and sought sponsors, usually businessmen from Bangkok; and (3) businesses or individual businessmen who purchased land in Samut Sakhon for speculation and used hired staff to create the ponds.

Surveys by NACA (1994) of the shrimp farming population found a lack of experience in either or both the biological or fisheries sciences. Also, the level of higher education and farm management training related to shrimp farming was correlated to farm performance and profitability. Generally, less informed or knowledgeable shrimp farmers failed first, lacking the necessary management skills required for the more intensive systems. As the local receiving environment degraded and became stressed farms with good management techniques, often only within the capability of the multi-national operations and beyond the scope of the small-scale farmers, prevailed. Only these farms could cope with the negative effects of the increasingly polluted external system.

Shrimp farmers, entrepreneurs in the true sense of the word, are willing to take risks. This was clearly demonstrated in Samut Sakhon by the many operations that developed

in high risk areas (i.e. poor site selection criteria). The prevalent attitude was that if the farms fail, then they will move on to a new site (if available) and abandon the land. As farms did fail, an increasingly complicating factor was the decreasing availability of favorable sites for development and the corresponding increase in the price of coastal land thus limiting the choice for location of the shrimp farms. This further exacerbated the use of marginally suitable areas with limiting biophysical support mechanisms. Regional degradation was clearly worsened by the "gold rush" psychology of the times.

The lack of dedication to responsible shrimp farming was illustrated by the values of some of the shrimp farmers. Even though they were aware that environmental problems would shut down the operations in the Upper Gulf they had already cynically explored 'new' areas in other regions prior to failure, thus ensuring some more land area for culture ponds. In Thailand, this has meant the wholesale development of Eastern and Southern shrimp farming regions following the Upper Gulf decline. The current area of interest to shrimp farmers is the Andaman Sea coast and the current intention of the Thai government is to limit or prohibit full scale shrimp farm development in this region before it is too late.¹³ This pattern of 'opportunistic' expansion by Thai investors is occurring in shrimp farming regions of other Asian countries as well. Chapter 6 will discuss this 'expansionist' aspect of shrimp farming operations.

5.8.7 Lack of regulation and inappropriate use of drugs and chemicals

Shrimp farmers in Samut Sakhon were observed to be deficient in knowledge of the use and the potential effects of chemicals offered to them for sale by commercial representatives.¹⁴ This lack of practical technical knowledge created the safety issues with respect to the chemicals used. In discussions with Thai shrimp farmers the

¹³ The Andaman coast (i.e. the western side of the Thai peninsula) contains 75 % of Thailand's remaining coastal mangrove forests (Remote Sensing Division, National Research Council of Thailand-IDRC/NRCT/RFD, 1991). The province of Samut Sakhon contains a meager 1 square kilometer. This figure is perhaps an over-estimation as the area of mangrove that remains in the author's opinion is in a severely degraded condition consisting primarily of immature mangrove trees along the smaller tributaries of the Thachin river.

¹⁴ As far as the author is aware there is no requirement for shrimp farms to be licensed to administer pesticides and similarly, there are no requirements for pesticide applicator permits. The only arrangements for controlling the use of chemotherapeutic agents in Thailand is the requirement to register the farm. The farmers are then advised to adopt good farming practices. The DOF has stated that they regularly conduct a surveillance program consisting of shrimp farm inspections to ensure that standards are being adhered to. At this point these measures have limited effect.

majority reported that they relied on the advice of the sales representatives or neighboring shrimp farming operations. Unscrupulous chemical salespeople, unenforced or deficient regulations in combination with the limited technical knowledge of the shrimp farmers have created the potential for serious problems.

A perfect example of the potential for disaster is the use of chloramphenicol in Samut Sakhon farming operations.¹⁵ The United States Food and Drug Administration (US-FDA) has restricted the use of chloramphenicol to cases where no substitute is available and has strongly recommended against use on livestock (Anon., 1994d). Unfortunately, shrimp farmers in Samut Sakhon unwittingly mix chloramphenicol with shrimp feed in the hopes that the drug will destroy bacteria in the shrimp ponds. Chloramphenicol is not effective in curing contagious diseases in shrimp as they will not eat feed laced with the drug. However, this drug is extremely hazardous to anyone who handles it and residues in the shrimp pose serious, possibly fatal, risks to consumers. The drug is not heat labile, thus the potency of the drug remains even after cooking and minute residues consumed repeatedly could have a deadly impact. The use of this substance is prevalent in other shrimp farming operations outside of Samut Sakhon despite human health concerns. The potential for damage to the shrimp farming industry as a whole would be long lasting if exported shrimp from a producer created illness in foreign consumers due to chloramphenicol.

5.8.8 Effects of other human activity: weak enforcement of pollution control legislation

Rapid industrial expansion has occurred in Samut Sakhon, in common with other Upper Gulf provinces. This region is now the favored location for industry and urban expansion due to the proximity of the Bangkok Metropolitan Region. During the field work for this thesis several areas previously utilized by intensive shrimp farming were converted to housing. These new estates, needed to house the growing population of the region, include all of the associated infrastructure development of upgrading of the road access systems, supply of water and electrical services. All of the existing cities and

¹⁵ Chloramphenicol is an antibiotic drug that was discovered in 1947 which was found to inhibit a broad spectrum of bacteria, being primarily bacteriostatic, as well as certain viruses and rickettsiae. It was utilized to cure communicable human diseases such as typhoid fever and some urinary tract infections. However, it was later found by physicians to cause symptoms of anemia through destruction of blood cells in the bone marrow. It has an even greater effect on children whose liver does not yet produce the enzyme to inactivate chloramphenicol.

industrial plants, including most of the new cities, continue to deposit waste directly into the water resources without treatment thus creating extensive pollution. These practices have had a significant impact on the shrimp farms of Upper Gulf Region. In fact shrimp farming will no longer be a regional activity and is generally relocating elsewhere. Due to this region being swallowed up by the expanding industrial heartland, shrimp farming could never have maintained the level of production achieved in 1989 for any length of time even if ecologically sound practices had been achieved. The alienation of food producing and natural land is the final irony of Samut Sakhon.

The extensive land development for other uses in Samut Sakhon does impact the interpretation of indicators of environmental quality related to intensive farms. A note of caution must be made on the concept of self pollution (negative effects from waste discharge).

Industry, urbanization and agriculture all contribute to water supply, and compete for available resources. Farms located near these developments will be more heavily impacted, and analysis of the factors affecting their success made more complex. The problem is common for food production. For example, in the Fraser Valley or the Okanogan Valley in British Columbia, the proximity effects of cities to agricultural practices makes the assessment of environmental impacts difficult.

5.8.9 Observed site specific limitations of the Upper Gulf region

This section examines biophysical factors contributing to the decline of shrimp farming in Samut Sakhon and the Upper Gulf region as a whole. The effects of coastal activities contributing to an increased level of marine pollution have been worsened by regional biophysical constraints (i.e. shallow Upper Gulf coast with poor tidal flushing and inadequate supply and discharge canal systems) and the effects of other human activity in the region. These biophysical factors in Samut Sakhon province may contribute to shorter shrimp farm cycles than would otherwise be experienced.

The shallow Upper Gulf, with its closed shape, is a region of poor water quality caused by the inflows from four major rivers that carry agricultural, domestic and industrial waste from Thailand's upland activities. Waters discharged from these rivers and canals cannot move a long distance from the coast and are trapped in a mixed

circulation of the "upper gulf" (Figure 7). The shallow, muddy coast with long narrow supply canals cannot supply enough water for adequate exchange and flushing. Thus, the source water quality was diminished due to the low rate of tidal flushing. This is supported by charts, personal observations (evidence that debris is not dispersed during tidal changes). The seasonal variation in the direction of the gulf currents results in dramatic salinity changes during the year, imposing climatic constraints that affect the performance of shrimp farms in the region.¹⁶

Self pollution was a significant factor in the failure of the Samut Sakhon and Upper Gulf shrimp farms. Under the influence of a semi-diurnal tide, pollutants in waste water which flowed out some distance during the ebb tide, and returned during high tide. The increasing number of farming operations and this repeated action led to a build up of pollutants. Thus, the pond culture systems relying on tidal flow or pumping, for water exchange, faced a gradual increase in water quality deterioration. The net result is that instead of replacing waste with clean water, farms recycled waste water (Chamberlain, 1991 and reported in Barg, 1992).

This phenomenon was a regular occurrence in the province of Samut Sakhon where the residues from the feed, chemicals and drug would be routinely discharged to the canals during water exchange or draining of the ponds during harvest. In Samut Sakhon the bottoms of the irrigation canals or canals dug by the villagers to stock the water for shrimp farming were usually lower than the average tides. Therefore, the farm residues would accumulate in significant quantities on the public canal where the waste water was discarded. The shrimp farmers normally pumped water from these canals into their farms until the canals were pumped dry. Therefore, the canal bottom residuals would be pumped back into the farms. In the early stages of development this problem was not critical because the number of farms in the area was not high. The canals still had the reserve capacity for the natural treatment of the water. However, as the number of farms increased the capacity of the drainage canals was exceeded beyond their assimilative capacity and the incidence of environmental problems increased. Such events have been described in various NACA reports including OEPP (1994b).

¹⁶ The shrimp farmers of Samut Sakhon have adapted to these seasonal fluctuations which cause extreme salinity and scarcity of water in the dry season and very low salinity and the potential for flooding in the rainy season. Cropping of the shrimp is timed to coincide with the periods between these two extremes.

Growing industrial pollution problems and associated environmental degradation have emerged as Thailand has experienced high economic growth, on average an annual, double digit GDP increase between 1987 and 1993. In particular, the Upper Gulf has experienced acute environmental problems generated by the rapidly advancing and concentrated industrialization of the Bangkok Metropolitan Region (BMR) and surrounding coastal provinces including Samut Sakhon. The land, air and water bodies, particularly rivers and coastal areas, are receiving pollution at levels far in excess of their assimilative capacity. Fifty-two percent of industries (76 % in terms of Gross Domestic Product) are located in the BMR. Coastal aquaculture in the region is presently seriously affected by these developments (Menasveta, 1987; Panayotou et al., 1990).

A wide variety of activities contribute contaminant inputs that are of concern to aquaculture operations (Table 5.8). Agricultural and agro-industrial plants in the suburbs of all coastal cities discharge organic residues into the waterways. These substances are toxic to plant growth and hazardous to fisheries. There are more than 10,000 small and large scale industries adjacent to the Chao Phraya, Thachin and Mae Klong rivers and bordering estuarine waters and coastline of the Gulf particularly in the area of Chonburi province. Products include sugar, tapioca, starch, alcohol, processed food products, fishmeal, meat and meat products. Other significant contributors to the pollution of the fisheries are the hard board mills, petroleum refineries, plastics factories and chemical plants. Added to these industrial effluents are point and non point sources of contaminants from domestic sources (sewage, run off from roadways). Few industrial or domestic waste streams are treated.

Table 5.8 Point and non-point sources of pollution within the coastal zone (Modified from Chua et al., 1989)

Activity	Prime Input
Port facilities	Oil slicks and domestic wastes
Urban settlements	Domestic wastes
Industrial sites	Heavy metals, chemicals
Beach resorts	Solid and domestic wastes
Sand mining, mollusk farms	High suspended solids
Shrimp, fish and cage farms	Pesticides, nutrients, high suspended solids and organic matter loading
Agriculture	Pesticides and nutrients
Reservoir freshwater discharge	Alters coastal hydrologic regimes
Piggery	High organic wastes and drugs

Contaminants include both organic and inorganic compounds, with toxic heavy metals and chlorinated organics present. These are summarized in Table 5.9 and described below. Many are priority toxins scheduled for virtual elimination in Canada and the U.S. The difficulty of determining the toxicity of complex mixtures (synergistic effects) is clearly apparent.

Table 5.9 Major contaminant inputs to the Upper Gulf

-
- Urban sewage (BOD, TSS)
 - Agricultural and agri-food waste
 - Pulp and paper (dioxins, furans, wood fiber)
 - Petroleum hydrocarbons (i.e. crude oil and its refined products)
 - Agricultural fertilizers (primarily nitrates and phosphates)
 - Heavy metals (cadmium, mercury, lead, copper, zinc etc.)
 - Halogenated hydrocarbons (DDT and other chlorinated hydrocarbons pesticides, polychlorinated biphenyl's (PCBs), etc.)
 - Radionuclides

Urban Sewage: A major contributing source of degradable waste is the uncontrolled discharge to the waters of domestic solid and liquid waste effluent from local communities. This is a major source of organic pollution in the populous areas and has strong implications for human health (Sosmena, 1994). In urban localities, particularly in coastal cities, solid and liquid wastes, primarily untreated sewage are poured into the rivers and are carried into the shrimp farming areas by tides. These degradable organic wastes are by far the greatest volume of discharge into the coastal waters and estuaries. For example, the most significant source of pollution in the Gulf of Thailand is that of the domestic waste effluent. Calculation shows that some 60 to 70 % of the total waste load in the Inner gulf stems from the communities adjacent to the rivers, estuarine waters and the coastline. There are few, if any, sewage systems or waste water treatment plants in Bangkok or its surrounding conurbation's. The discharges contain the heavy concentrations of BOD matter, suspended solids and pathogenic bacteria (BOI, 1993).

Agro-processing sector: The agro-processing industry in Thailand is set for long term expansion and in 1990 over 5,000 agro-industrial establishments of all sizes were operating in Thailand (BOI, 1993). The key subsectors of the industry include food and beverages, tobacco, leather, wood and paper products. While contributing significantly to economic growth of the country, agricultural processing also generates vast quantities

of solid and liquid wastes. In a survey of 5 frozen seafood plants, the flow of wastewater ranged from 30 (small plant) to 1,200 m³ /day for larger operations (BOI, 1993). The BOD resulting from excess material outflows ranged from 430 to 2,100 mg/L respectively. These particular outflows fall far beyond the acceptable BOD standards (at 20 to 60 mg/L depending on the BOD intensity of the activity) set by the Department of Industrial works in early 1993.

Agriculture Agricultural activity is a significant source of pollution in the Gulf area. Large amounts of fertilizers and pesticides are used each year in the production of rice, sugar cane, fruit and vegetables. Drainage from the cultivated areas enters the river basins carrying nitrates and phosphates in significant quantities. Accumulations of pollutants in the estuarine waters are usually high during the rainy season.

Petroleum hydrocarbons in sea water, sediments, and biota: Petroleum pollutants, in the form of oil spills, slicks and tar balls are a growing problem along the coast and the seashore. A Harbor Department study in 1989 reported 14 oil spills during the period 1973 to 1990. Most of the spills were furnace oil into the Chao Phraya river of unknown quantity and sources. There is little information on the effects of hydrocarbons on aquaculture products to suggest specific hydrocarbon levels that would render a site or product unsuitable. Sompongchaiyakul et al. (1986) measured the level of petroleum hydrocarbons found in sea water, sediments and the biota of the Gulf of Thailand. The level of petroleum hydrocarbons in sea water, sediments and biota, are recognized as important in understanding the overall environmental quality of the Gulf of Thailand.

5.9 The search for sustainability: observed responses to shrimp farm failures and productivity declines

5.9.1 Introduction

Responses to shrimp farm failure in the province of Samut Sakhon indicate the diversity and resourcefulness of its inhabitants. The main response to failure initially was abandonment or suspension of shrimp culture operations. Many of these farms remain derelict and unproductive in their present state. The field observations of land use activities in Samut Sakhon for this research were completed during in-province fieldwork

that occurred in the period two to three years following the large scale abandonment mentioned above. Discussions with small-scale farmers revealed that many of their intentions regarding the land use of failed shrimp farms are not economically feasible. In addition, the capabilities to switch back to previous land use is not feasible due to the degraded nature of the sites. Only larger companies with sufficient capital resources have the option to move farm location to more 'favorable' areas to re-establish new culture operations. Table 5.10 presents the author's observed responses of the shrimp farmers following the provincial failure.

Table 5.10 Observed responses of the shrimp farmers following the failure of shrimp farm cycles in Samut Sakhon and the Upper Gulf region¹⁷

-
- **Land development:** Main purpose of land acquisition with no genuine interest in shrimp farming beyond holding land for speculative purposes. Activity of shrimp farming only short-term activity for land use while price of land increased in the region.
 - **Change land use:** Alter shrimp culture methods by changing species, or intensity (i.e. to extensive or semi-intensive); commence fish farming; crab fattening; sedimentation-pond operations. ¹⁸
 - **Abandonment or leave land fallow:** Greater than 90 % of area originally under intensive culture (based on unpublished NACA reports for 1993).
 - **Migrate or relocate:** Move to another culture area for another culture operation (i.e. to southern or eastern Thailand); only an option for larger companies.
 - **Alternate employment and poverty:** many of the land owners have had to find out-of-region employment and change occupations to avoid loss of land due to bank foreclosure on loans secured to commence shrimp farming.
 - **Remediation:** Pond remediation tasks on-site (i.e. development of closed culture systems); Status of mangrove replanting or other coastal ecosystem remediation is occurring in limited applications.
-

As would be expected some of the responses are more popular than others with remediation being the response least observed. There was a noticeable difference between actual 'observed' responses to the stated 'intentions' for land use by the shrimp farmers. A NACA survey in 1994 found that 73 % of the shrimp farmers have continued interest in returning to shrimp culture (Table 5.11). Throughout the author's fieldwork it was noted that the various responses to shrimp farm productivity collapses are primarily viewed as the non-desired land use. Shrimp culture, although an unrealized land use for the moment and perhaps for the future, remains desirable to the urban occupants of Samut Sakhon primarily because of the economic profits once

¹⁷ Information based on field investigation and interviews with Thai shrimp farmers conducted from September 1993 to December 1993 and September 1994 to April 1995.

¹⁸ This operation is unique to the Upper Gulf region and is primarily due to the shallow muddy conditions of the Upper Gulf coastal areas.

available and the continuing desire for shrimp products. Paradoxically, urban expansion is actually foreclosing this lucrative option.

Table 5.11 Intentions of Samut Sakhon shrimp farmers who have 'abandoned' their land (OEPP, 1994b)

Details	No. farms (n=52)	(%)
Return to shrimp culture	38	73
Culture fish (Seabass)	1	2
Salt farming	4	8
Sell land	3	6
Abandon the land	2	4
Agricultural land, housing estate and rent land	4	8

5.9.2 Land development and speculation

Rapid expansion and development of the Samut Sakhon region has led to a dramatic increase in coastal land prices tempting many of the shrimp farmers to sell their land (Kikuchi 1993). The expansion of Bangkok and its suburbs consumes land for housing and industrial development. Abandoned shrimp farms sites lend themselves to such development as no land clearing is required. Additionally, the developers of these urban and industrial estates are not concerned with the soil and water quality of the region. Human settlements are not dependent upon the ecosystem support mechanisms to the same extent as shrimp farming. Any remaining considerations are virtually all human health in focus.

Prior to urban expansion, the rapid growth of shrimp farming resulted in intense competition for valuable and increasingly scarce coastal land. This competition contributed to more intense production process which in turn led to escalation of the cost of coastal land. The shrimp farm investors felt the need to maximize profits per unit area. This increase in the price of coastal land is one of the effects of coastal aquaculture and an economic factor in land use decisions (Table 5.12). Figure's 23 and 24 present images of the land use activities that are occurring in the abandoned shrimp farming areas.



FIGURE 23. URBAN ESTATE DEVELOPMENT USING ABANDONED SHRIMP FARMING AREA



FIGURE 24. PITTHAYALONGKORN CANAL AND EXTENSIVE SHRIMP POND IN THE BACKGROUND. THE HOUSE IS OCCUPIED BY A PREVIOUS SAMUT SAKHON INTENSIVE SHRIMP FARMER

The price of coastal land in the Upper Gulf region prior to 1963 was only \$US 643 /ha. The per hectare price increased sharply from \$US 2,572 in 1985 to \$US 25,720/ha in 1989 (Hanvivatanakit, 1989 and cited in Phillips, 1994) The current land value per hectare is \$ 51,440.¹⁹ In other shrimp farming provinces the value of coastal land is not as high and lends support to land speculation. Changes in land use in Samut Sakhon for various years illustrate the effects of land speculation, including the transfer to, and removal from, aquaculture use.

Table 5.12 Coastal land prices (\$US /ha) prior to and after shrimp culture development for various provinces (OEPP, 1994a,b; Hanvivatanakit, 1989)

Province	Year	Price of land/ha
Samut Sakhon	1963, before culture	643
	1985 - 1989	2,572-25,720
	1994	12,860 - 437,243
Chanthaburi	Before culture	51-129
	1991	1,286-2,572
Nakhon Si Thammarat	1994	12,860-18,004

The provincial land area designated as 'swamp' changed dramatically during the period 1982 to 1990 from 4,358 ha in 1982 to 676 ha in 1987 and to 4,268 ha in 1992 (Table 5.13). In 1992 the combination of land designated as 'swamp' and 'idle' was 29,473 ha (23,066 of which was in Amphoe Muang district). This change was due to a boom in the land market during this period which resulted in investors buying up land which was then left as swamp and idle land. This was the first time speculation in rural land was not limited entirely to areas near urban centers. Consequently, land area of failed shrimp farms was left derelict after crop failures and held for speculation.²⁰ There was no rush to replace 'abandoned' shrimp farms with other potentially productive land uses. Shrimp farming was viewed as an income generating activity during which the land value on which it was conducted increased dramatically.

¹⁹ The original figures were converted from Baht/rai to \$ US/hectare. The currency conversion was 25 Thai Baht per Canadian dollar and 1 rai equals 0.16 hectares.

²⁰ It may be argued by economists that speculation is productive. However, the author would suggest that this purely 'economic' view towards the land is narrowly focused and does not consider the fact that the damaged sites from shrimp farming reduces all future potential of the land for other uses. For example, the land alienation from food production. The land has only increased in value for investors of urban and industrial estates and not for the local inhabitants of the province.

Table 5.13 Changes in land designated as swamp and idle land in the province of Samut Sakhon for various years (Popan, 1994)

Land use designation	Year	Area (ha)
Swamp	1982	4,358
	1987	676
	1992	4,268
Idle land	1982	0
	1990	1,701
Swamp and idle	1992	29,473
	1992 (Muang District)	23,066
Urban	1982	1,021
	1991	1,479
	1992	4,717*

Note: * Some of the urban area increase resulted from changes in the designation that saw the inclusion of industrial areas into the urban area limit (i.e. this 4,717 ha included the 1,291 factories that occupied 719 ha leaving the urban area without factories at 3,998 ha).

5.9.3 Fish farming operations

Some owners of failed shrimp farms in Samut Sakhon have turned the 'idle' ponds to fish culture and crab fattening. These alternatives can quickly, with minimal cost and modification, bring idle land back into some form of production (Table 5.14). Fish culture requires similar management arrangements to shrimp culture and so is an activity that is readily familiar to the shrimp farmer and in some cases was the previous occupation of the shrimp farmer. The main fish cultured are Nile Tilapia (*Oreochromis niloticus*) but others like the grouper (*Epinephelus* species), sea breams (porgies), sea bass (*Lates calcarifer*), mullet (*Mugil* sp.), and milk fish (*Chanos chanos*) are possibilities for culture and are being actively promoted by the large former shrimp farming companies in the region. This interest suggests these operations may be economically viable.

Various Nile Tilapia fish farming operations were visited throughout the field research (e.g. C.P. Sahakorn fish farm). Tilapia are resilient and can grow in the poor water quality conditions now prevalent in the Upper Gulf region. The fish are produced for local markets of Samut Sakhon in which there are no distribution problems after harvest.

Table 5.14 Typical fish farming operation parameters utilizing an abandoned intensive shrimp farm in the province of Samut Sakhon, Thailand, December 1994 (C.P. Sahakorn fish farm)

Species	Nile Tilapia (<i>Oreochromis niloticus</i>)
Stocking density (pieces/m ²)	2.5
Grow-out pond size	Same as shrimp pond; little conversion required; small fish pens within the ponds
Water exchange frequency	Once per week
Culture period (months)	3
Size of fry during stocking (g)	250
Harvest size (g)	>400
Local market price per piece (\$ CAD)	1.17
Salinity (ppt)	12 to 13
Feeding rate and amount	80 to 100 kg/day during 4 meals
Feed used	Same as shrimp feed (CP 905)
Ownership	Large company (C.P.); foreign manager
Size of operation	8 ponds @ 0.72 ha each

5.9.4 Crab fattening operations

In the wake of shrimp farm failures Thailand has identified the mangrove mud crab *Scylla serrata* as a species with commercial potential due to considerable domestic and export market demand.²¹ Thailand has experienced a steady decline in natural populations and an increasing ratio of small undersized crabs in the marine capture (Csavas, 1994c). Traditional production techniques are based on captured stock; captive breeding of the mud crab is not yet commercialized. Efforts to produce hatchery reared seed and implement mass production techniques are currently given a high priority.²² Entrepreneurs started using Samut Sakhon as a staging area for imported mud crabs by stocking them in abandoned shrimp ponds. The volume of mud crab peaked with 223 MT of production in 1986 when there were more than 100 small crab farms in Thailand. These, however, almost disappeared when suitable coastal lands were converted to more profitable shrimp farms. There are no current production data but in 1991 only 4 MT of cultured crabs were reported (Csavas, 1994c).

²¹ Cage culture for local spiny lobster species (*Panulirus ornatus*, *P. vesicolor*, *P. longipes*) have been tested and found to show promise. Like the mud crab, current efforts are aimed at raising small captured individuals to marketable size.

²² The fact that researchers are examining ways of mass production for this species of crab suggest that a similar intensification of methods for crab culture may follow. The desirability as a food product and high price for the crabs adds further incentive.

The procedure for fattening the crabs is quite simple and the conversion from shrimp grow-out to crab grow-out pond requires little or no investment cost. Post-molt, thin, "watery" crabs of marketable sizes (1 to 4 pieces /kg) are brought in from Vietnam and "fattened" for a period of 10 to 20 days in Thailand and then sold to markets in Hong Kong. Locally, the price for such crabs are \$13.90 /kg and in Hong Kong \$22.50 /kg. The crab fattening operations in Samut Sakhon can utilize the abandoned shrimp ponds directly and are only slightly modified to make a culture area of 500 to 800 m². This area is then enclosed by a bamboo fence to prevent escape and the water depth in the pond is maintained around 1 meter. A mud island is provided in the center into which the crabs burrow. The investment return from crab culture was reported to be as high as \$ 54,413 /ha and compares favorably to the income earned from shrimp farming (OEPP, 1994b).

5.9.5 Changing the intensity of shrimp culture

In discussions with Samut Sakhon shrimp farmers the author determined that most farmers would prefer to continue shrimp farming. In response to these intentions some farmers have either altered the intensity of culture (normally lowered) or changed species. Evidence of this response to intensive shrimp farm failure in Samut Sakhon was clearly demonstrated. Of the 1,150 shrimp farms operating in 1992 over 1,039 were extensive and 25 were semi-intensive operations (Table 3.22, data from DOF, 1994).

Extensive shrimp culture, popular only to shrimp farmers with sufficient land area, requires only minor earth dike modification. However, the field staff from the Samut Sakhon Coastal Aquaculture Development Center (CADC) promote semi-intensive culture over extensive. This suggestion is intended to increase shrimp production with minimal environmental impact and release more land for other uses. The success of semi-intensive operations has yet to be determined.

The environmental constraints of the region limit possibility for a region-wide return to the previous level of activity with intensive shrimp farming. The field staff of the CADC have estimated that 30 % of the operating shrimp farms in the province should be intensive. As of 1992, intensive farms operated only 2.4 % (174 out of 7,395 ha) of total cultured area representing just 7.5 % (86 out of 1,150 farms) of the total number of farms (DOF, 1994b).

5.9.6 Changing the shrimp species cultivated

As in Taiwan, some of the shrimp farmers in Thailand have switched the shrimp species cultivated. *Penaeus monodon* was originally chosen both for its high market demand and ability to withstand difficult and changing water conditions. Alternate species being cultivated are *Penaeus penicillatus*, and the kuruma prawn, *Penaeus japonicas*. Switching cultivated species was attempted in Taiwan following the crash of culture in 1988. Although some positive results have been obtained in the short-term, the end results has been the same (Chen S.N., 1995).

5.9.7 Conversion of derelict shrimp farms to salt farming operations

The province of Samut Sakhon is a traditional salt farming region with 37 % of the land currently utilized for shrimp culture being previously utilized for salt production (OEPP, 1994b). Some salt farm operations still exist amongst the shrimp farms. In the neighboring province of Samut Songkhram there are many salt farm operations. In the haste to convert to intensive shrimp ponds few of the salt farmers considered the possibility of ill consequences in shrimp farming. Now, for many, the cost of conversion back to salt pan is prohibitive or is too late. A study by NACA in 1994 calculated the costs for this conversion (reported in OEPP, 1994b).

The land use pattern has, in many instances, been from salt pan converted to extensive shrimp farm to intensive shrimp farm and back to salt pan following the shrimp farm failure. One benefit of conversion to salt pan operation, over other land use conversions, is that the soil conditions of abandoned shrimp farms, prohibitive for agricultural use, makes salt farming one of the few alternatives for land use. However, conversion from shrimp to salt farms is not viable based on the limited markets for the salt produced and the low value of salt product.

5.9.8 Sedimentation-pond operations for topsoil production

The coastal waters of the Upper Gulf are characterized by an extremely high degree of suspended materials. Some land owners in the tidal flats flood large areas and retain the water to allow the suspended matter to settle. After a sufficient settling out time the water is changed, generally with the next tide, and the procedure is repeated. The impoundment's are eventually pumped or left empty and the accumulated sediments are allowed to dry for a few weeks. Accumulated materials are then harvested (using machinery) and sold to land developers as fill material. Field investigations in 1994 and 1995 found that one large dump truck load of sediment is valued at \$US 21.

Landowners in Samut Sakhon are conducting this operation adjacent to urban and industrial estate developments. Although it generates some income where there is essentially none this operation is not viewed as a long term activity and can only be considered as a temporary response to shrimp farm failure. It does not resolve any of the problems associated with the failure of shrimp culture other than replace the activity with an income generating activity. For the short-term however, sediment operations provide fill materials for urban expansion into areas previously utilized for shrimp ponds.

5.9.9 Relocation inland in the same region

The short-term profits possible with shrimp farming has resulted in very rapid expansion of supra-tidal land use. New entrants seeking quick returns create extreme pressures to construct ponds on supra-tidal land which is often only marginally suitable for shrimp farming (Phillips, 1994).

Shrimp farmers may be the original land owners or lease land for the shrimp farm operation. Shrimp farmers that lease land (i.e. the lessee's) often do not explain to the land owners the significant and potentially irreversible changes to the land as a result of shrimp farming. This leads to potential conflict when the landowner reoccupies the land and attempts to adopt the previous land use activity only to find the suitability for other uses has declined. For example, the salinised soils may be unsuitable for rice paddy culture in post-shrimp farming land use.

This preference for *supra tidal* land has gone one step further. Normally, the ponds are located on *supra tidal* land reasonably close to the coast. However, the increasing pollution of coastal water supplies has led to some shrimp farming operations relocating inland. The shrimp farm at Sample Station 2, located more than 10 km from the coast, is an example of such relocation inland. Relocation is prompted by the desire to avoid the problems of 'self-pollution' encountered by high farm densities in coastal areas. The established trend now is to relocate inland, further than any previous farm, into non-conventional or non-coastal shrimp farming areas. Other new entrants to shrimp farming have been attracted by the 'success' of these operations and have avoided the coast altogether and established initial operations inland. These operations, by virtue of their location and available water supplies, are characterized as 'low-salinity' operations. The shrimp farmers have been able to create the required salinity in the culture ponds to grow shrimp, *albeit* at a much lower salinity than recommended.

The operating procedures of these farms are unique to Thailand and Samut Sakhon province. The procedure utilized to stock the earthen ponds at Station 2 required the purchase of high salinity effluent (around 200 ppt) from local salt farm operations.²³ The salt farmers truck this hyper saline water to the culture ponds. This high salinity water (often termed "hyper saline") is then diluted in the ponds with available fresh canal water to bring the final salinity to around 6 to 7 ppt. The end result is a low-salinity mix which contrasts markedly with the previously desired salinity value of 30 ppt (i.e. the salinity of full strength sea water). The earliest shrimp farms of this type have demonstrated 'success' in terms of productivity over the long-term (i.e. they have continued to operate while the majority of the coastal farms failed).

However, the operation of shrimp farms in predominantly agricultural areas has potentially serious impacts on the other land uses in the region through contamination of freshwater sources, discharge of high BOD waste effluent and increased salinity of the soils. These environmental impacts may sustain very long-term damage to the surrounding ecosystem of the region. The shrimp farm surveyed in this research is surrounded primarily by agricultural land uses creating the potential for land use conflict over the shrimp farm discharge of saline effluent into the freshwater canals. The shrimp farmers are aware of the serious environmental impacts to other land uses. The

²³ Salinity is defined as the total amount of solid materials in grams contained in one kilogram of sea-water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine and all organic matter completely oxidized. The unit ppt (‰) is parts per thousand, the common unit for expressing salinity strength.

consensus among similar shrimp farms in the region is to keep operating as long as the shrimp crops are surviving. The trend exhibited by Thai shrimp farm operations obviate the need to adopt sustainable practices and is not a recommended solution to the present problems of shrimp farm failure on the coasts of Samut Sakhon. During the fieldwork there were crop failures in similar operations indicating that the success of this type of shrimp farming may be short lived.

5.9.10 Migration to a new site out of region

One of the options available to the larger shrimp farming companies, (such as Charoen Pokphand Aquaculture), and other independent shrimp farmers with sufficient capital is to relocate to other areas of Thailand to the East and South of the Upper Gulf region. The farmers are now beginning to move their operations to western Thailand on the coast of the Andaman Sea which is still largely mangrove forest (75 % of Thailand's mangrove forests) and supports a rich capture fishery. The Andaman coast is the most sought after location in Thailand for the expanding shrimp industry. The results of 'efforts' by the Thai government to protect this coast from the expansion of shrimp farming have merely been to slow its pace. These areas are now subject to the familiar pattern of the expansion and intensification of culture methods similar to those experienced in the Upper Gulf. Although these areas offer better cultivation conditions than the Upper Gulf the same problems with declining productivity and crop losses are occurring in the Eastern and Southeast shrimp farming regions. Site rotation of shrimp culture operations appears to be one viable consideration for these shrimp farming areas.

5.9.11 Site rotation and fallow areas

Site rotation, changing culture intensity, or switching species may offer improved culture environment conditions. In 1993, for example, a deteriorated shrimp farming area in eastern Thailand regenerated after the intensity of culture changed for a few years. This situation allows for fresh and turbid water discharges to settle and coat the existing polluted layer of the river/gulf beds. Eventually, the water sources in these areas improved. This may work well in Eastern and southern Thailand but does not favor the central region due to the unavoidable industrial and urban developments. This practice can be compared to the practice of shifting cultivation in agriculture.

5.9.12 Restoration, rehabilitation and remediation of derelict shrimp farms

There have been few efforts to improve areas that have been abandoned in the post intensification phase of shrimp farming. In discussions at NACA it was discovered that several projects have begun to focus on the feasibility of re-establishing some mangroves in Samut Sakhon. Pilot projects have been established and are ongoing. To date no results from these studies have been reported (personal communication, D. Macintosh). The availability of money and technical limitations in the methods appropriate to restore abandoned areas in Samut Sakhon are recognized constraints. Such efforts are critical for Samut Sakhon where there is an estimated 1 km² of mangrove area remaining and more than 90 % of the shrimp operations which have failed and remain derelict (Abandonment data is from unpublished NACA reports, 1993).

5.10 Summary of responses to shrimp culture collapse

The responses by farmers and investors that have been presented are varied and largely short term and reactive. Given their diversity they are difficult to summarize. One technique, as described in the introduction (Chapter 1) is the use of a report card - to present trends in either environmental impacts or socioeconomic responses. Such report cards are largely subjective in judgment. In Table 5.15 a provisional sustainability report card is presented to illustrate this approach as applied to shrimp farming. A caveat is necessary, such presentations have the value of presenting a snapshot, but lack quantitative or substantive basis for the assignment of the trends. Recalling the definition of sustainability to be applied to shrimp farming (Chapter 1), it is suggested that most of the observed responses to shrimp farm cycle failure in the case study have been **negative** in terms of progress towards sustainability. The only responses viewed as positive in terms of sustainability were changing intensity of culture (lowering) and restoration. *Neutral* responses were considered to be interim solutions in terms of sustainability. The long term sustainability of these responses will be discussed in Chapter 6.

Table 5.15 Sustainability report card of observed responses to shrimp farm cycle failure in Samut Sakhon

Responses to shrimp farm failure in Samut Sakhon	Direction towards sustainability*
Land development and speculation	Negative
<i>Fish farming operations</i>	<i>Neutral</i>
<i>Crab fattening operations</i>	<i>Neutral</i>
Changing intensity of shrimp culture	Positive
Changing the shrimp species cultivated	Negative
<i>Conversion of the derelict shrimp farms to salt farming</i>	<i>Neutral</i>
Sedimentation-pond operations for topsoil production	Negative
Relocation inland in the same region	Negative
Migration to a new site out of region	Negative
<i>Site rotation and fallow areas</i>	<i>Neutral</i>
Restoration, rehabilitation and remediation of derelict shrimp farms	Positive

Note: *Negative-Unsustainable; *Neutral*-Interim solution; Positive-sustainable

6. THE SUSTAINABILITY ASSESSMENT: OVERCOMING BARRIERS AND EXPLORING OPPORTUNITIES FOR ACHIEVING SUSTAINABILITY IN THE SHRIMP FARMING INDUSTRY

6.1 Introduction

A "state of sustainability" report based on the framework introduced in Chapter 1 provides a useful basis for coordinating the author's field experience in Thailand. The information was collected through field investigation, writing cooperative research report reviews while at NACA, participation in NACA field studies, and discussions with fellow researchers. All of these experiences were combined with existing reference materials, previous policy assessments, and the experimental results of the present study to provide an analytical perspective. The present chapter will review the status of sustainability assessments for aquaculture. The main emphasis of the Chapter will be to:

- Identify a set of indicators and examine trends in their application to the shrimp culture industry.
- Introduce and critically examine the barriers revealed by these trends within a framework of institutional factors.
- Use this framework to perform a strategic analysis of sustainability and suggest practical solutions to overcoming the currently established barriers.

6.2 State of aquaculture sustainability assessment

Intensive shrimp aquaculture had not previously been extensively analyzed within a sustainable model or framework, prompting the author to organize the results of the case study using such an approach. In fact, an initial search revealed an absence of strategic planning in general for this industry.

Guidelines for planning the development of sustainable aquaculture have only recently been proposed (Barg, 1992; Chua, 1992; Pullin, 1993). Few analytical studies provide

specific policy recommendations (Barg, 1992; Parks and Bonifaz, 1994). Policies that address sustainable development and make sustainability recommendations have been proposed by Csavas (1994d) and examined by Rosenthal (1994). The sustainability of aquaculture in the Asia-Pacific region was a key theme in recent NACA reports that examined the environmental assessment and management of aquaculture development (See OEPP, 1994a,b). The Thai component of these regional studies focused on shrimp farming in southern Thailand (Hua Sai district in Nakhon Si Thammarat province and Ranot district in Songkhla province) and the Upper Gulf provinces of Chanthaburi and Samut Sakhon. Their reports make recommendations towards the establishing of environmental management plans for marine shrimp culture. Other studies by Jitsanguan and Mungkung (1993) have focused on the sustainability of coastal shrimp cultivation at Pak Phanang Bay Thailand; Padilla and S. De Los Angeles (1992) examined the economic development and the sustainable development of coastal resources in the Philippines; Davies and Afshar (1993) have compared the performance and sustainability of traditional and semi-intensive systems in Indonesia against a range of criteria, both socioeconomic and biophysical. These reports have provided background information on the status of sustainability assessment for this research.

These initiatives have recognized the importance of developing internationally accepted principles and standards that are not detrimental to natural resources, ecosystems and human communities. With this in mind, the "Declaration of Cancun" established that the FAO is in the process of establishing an international code of conduct for responsible fishing, in which one chapter will be devoted to aquaculture (Csavas, 1994d). This task is made difficult by both the lack of information on environmental impacts, and generally poor understanding of the carrying capacity of aquatic ecosystems. This question of the growth and sustainability of aquaculture has prompted researchers to ask basic questions regarding the value of its contributions to the global food supply (Pullin, 1995).

In Thailand, the case study revealed that access to information and barriers to acquiring it by research were also a critical factor in the sustainability assessment. Rudimentary consideration of a sustainability framework has been absent. Such consideration has generally been avoided by a typical 'frontier industry' development mentality prevalent in the shrimp farming areas. The case study of shrimp farming has highlighted a recurring dilemma in international development, international aid and investment: often no strategic planning based on sustainability principles is in place.

Analysis using a sustainability framework allows questions to be posed that determine the scope for 'growth' or reasons for 'contraction' of the industry: Consider the traditional approach where a single question is asked. Pullin (1995) has stated that:

"The vast majority of policy makers and developers, agencies, researchers, producers and consumers, ask questions about the future of aquaculture based on a single premise: how can enough farmed fish be produced to fill the gap between supply from stagnating or declining capture fisheries and the increasing demand in developed and developing countries?"

The statement indicates a traditional 'demand-and-supply' approach in common with many resource dependent industries. The concept is purely 'market oriented' in a 'natural resource management' context. The questions asked from a sustainability starting point are different: Is the new development viable in the long-term? Is the development at the expense of other interests and values? Does it help the home country?; Does it help the consuming country?; Is it a good model for other developing countries to emulate (Odum, 1991)?

Aquaculture needs to be critically evaluated in relation to major developmental issues and to determine the extent to which it be compatible with the concepts of 'sustainable development'. Similarly, traditional methods of single environmental indicator comparisons need to be broadened to incorporate other social, economic and ecosystem measures (Davies and Afshar, 1993). Fundamental shifts in resource utilization that incorporate 'ecosystem-based management' concepts are urgently required.

In summary, all forms of economic and social activity make demands on the resource base, whether agricultural production, aquacultural production, industrial production or human settlements. If such activities are to be supported in the future, there is a need to ensure that resources are used with the greatest efficiency, that the by-products of these activities do not negatively impact the environment. The call for 'sustainable shrimp farming' will be the product of a change in attitude to regard both farm development and the environment as interdependent concerns. In common with other global resource industries, shrimp farming has to make a fundamental shift towards 'ecosystem-based' management methods. Hence the sustainability assessment in chapter 6 has broader implications and application than just a case study of shrimp farming.

6.3 Choosing indicators to assess intensive shrimp aquaculture systems

Previous research comparing intensive monoculture systems to ecosystem function have identified a number of possible indicators for assessing intensive aquaculture systems. The complex and subtle effects of stress on ecosystem structure and function have been discussed by Odum (1985), and these characteristics have been compared with those of monocultures by Folke and Kautsky (1992). Such comparison provides insight on the ecological effects of shrimp farming - an intensive monoculture and has influenced the authors selection of indicators for the sustainability analysis. Many, if not all, of these factors were evident in Thai intensive shrimp aquaculture operations (Table 6.1).

Table 6.1 Similarities between stressed ecosystems and intensive monocultures as identified by Odum (1985) and Folke and Kautsky (1992)

-
- High dependence on extra energy and short residence time of energy
 - Increase in exported or unused primary production
 - Increase in nutrient turnover and nutrient loss
 - Decrease in resource use efficiency
 - Increase in growth-strategy species
 - Increase in parasitism, diseases and other negative interactions
 - Increase in horizontal one-way transport and decrease in vertical cycling
 - Few, simple, rapid open (leaky) cycles
 - Shortening of the food chains
 - Network with low average mutual information
 - Simple structures with few hierarchical levels
 - Low complexity, low diversity, low system efficiency
 - Throughput-based systems due to reduced internal cycling

Based on the similarities described in Table 6.1, choosing appropriate indicators for intensive shrimp aquaculture systems parallels choosing indicators of ecosystem integrity. A note of caution should be mentioned. The complexity of ecosystems and the lack of a highly developed ecosystem model for the intensive farm operation in Samut Sakhon makes the selection of indicators provisional and subject to revision. In this case study, the present author chose indicators that illustrated negative trends in the intensive shrimp farming industry, as a whole.

6.4 Indicators of negative trends in Thai intensive shrimp aquaculture systems

For sustainability indicators to be usefully applied in this case study they should be easy to interpret, timely, and relevant to the Thai situation. The resulting organization and simplicity of the information makes them a useful tool in the sustainability assessment of shrimp culture. As Folke and Kautsky (1992) demonstrated, there are many indicators available. The indicators, chosen for the negative trends they track, follow from extensive field experience in Thailand and are those most appropriate for the Thai intensive shrimp aquaculture industry. Some of these indicators will be discussed below in the sustainability analysis. For presentation they are subdivided into farm operations, ecological impacts and socioeconomic effects (Table 6.2).

Table 6.2 Selected indicators of negative trends in Thai intensive shrimp aquaculture systems

Farm operations
<ul style="list-style-type: none"> • Production levels • Artificial feeds and waste production • Dissolved oxygen requirements • Biophysical resource (e.g. water and power) requirements • Importation of exotic shrimp species • Unlicensed use of chemicals antibiotics, pesticides and other chemicals • Number of unlicensed farm operations • Farm cycle performance (i.e. disease and viral problems) • Farm system performance • Production, number of units, and area cultured per km of coastline
Ecological impacts
<ul style="list-style-type: none"> • Land salinization • Land subsidence • Loss of habitat/natural areas (mangrove) • Effluent discharge to external environment • Nutrient enrichment and eutrophication of receiving waters • Persistence and the toxicity of chemicals to non target species
Socioeconomic effects
<ul style="list-style-type: none"> • Change in goods and services from mangrove systems • Availability of land for all uses • Change in land values • Change in agricultural production • Investment in shrimp farming development

6.5 Current negative trends in indicators

The negative trends in indicators are presented together with the critical factors in sustainability (Table 6.3).

Table 6.3 Indicators and associated trends and critical factors (barriers and opportunities)

1. FARM OPERATIONS INDICATORS
<ul style="list-style-type: none"> • Production levels • Artificial feeds and waste production • Dissolved oxygen requirements • Biophysical resource (e.g. water and power) requirements • Importation of exotic shrimp species • Unlicensed use of chemicals antibiotics, pesticides and other chemicals • Number of unlicensed farm operations • Farm cycle performance (i.e. disease and viral problems) • Farm system performance • Production, number of units, and area cultured per km of coastline
Negative Trends
<ul style="list-style-type: none"> • Poor subscription of farmers to the permitting process • High use of unlicensed pesticides • Increasing evidence of harmful substances in shrimp products in open Thai markets and export products (e.g. detection of antibiotic residues) • Decreasing production (regionally and provincially resulting from farm cycle failure) • Increasing numbers of abandoned operations • Increasing reliance on artificial feeds and single pass open or flow through systems that export waste products to the external ecosystems • More regular occurrence of highly virulent diseases (e.g. Yellowhead)
Critical Factors: Barriers/Opportunities
<ul style="list-style-type: none"> • Inadequate life cycle design; use life cycle analysis; design and operation of farming systems • Failure to value environmental integrity of supporting ecosystems • Control of chemical use • Improving feed management • Implementing ecologically integrated technology • Implementing treatment methods for farm cycle
2. ECOLOGICAL IMPACT INDICATORS
<ul style="list-style-type: none"> • Land salinization • Land subsidence • Loss of habitat (mangrove) • Effluent discharge to external environment • Nutrient enrichment and eutrophication of receiving waters • Persistence and the toxicity of chemicals to non target species

Table 6.3 (continued)

Negative Trends

- Water and soil salinization and land subsidence
- Loss of habitat; destruction of coastal mangrove ecosystem function; loss of biodiversity
- Land alienation and increasing numbers of abandoned unproductive areas

Critical Factor: Barriers/Opportunities

- Monitoring and environmental enforcement
- Effective waste treatment
- Water management regimes
- Protected areas and conservation strategy
- Environmental planning and impact assessment

3. SOCIOECONOMIC EFFECTS INDICATORS

- Change in goods and services from mangrove systems
- Availability of land for all uses
- Change in land values
- Change in agricultural production
- Investment in shrimp farming development

Negative Trends

- Decline in domestic food crops
- Increased production of shrimp products with continued support from lending institutions, national government policies and consumers
- Increased competition for land, credit, and commercial products
- Privatization of resources, the displacement and further marginalization of coastal communities (primarily the small-scale peasants and fisherman) in the communities where shrimp farms are established

Critical Factors: Barriers/Opportunities

- Role of non government agencies, communities in the shrimp farms development process
- Access to information from different perspectives
- Remediation of abandoned areas; re-establishing mangrove and other ecosystem support mechanisms

6.6 Analysis of selected indicators

Evaluation of the results of field observations has led to the identification of key indicators that can be tracked in evaluating progress in moving toward sustainability. Currently many of these indicators are in steep decline (negative).

6.6.1 Key indicator #1: environmental (change in habitat/natural areas: mangrove)

The correlation between increase in shrimp farming area and loss of mangrove area/viability can be directly applied to situations where shrimp farms are the first

entrants to the mangroves.¹ Since the area utilized for the shrimp farm development may involve the removal of mangrove areas, it serves as an excellent indicator of the expansion of shrimp farming. Access to accurate land use information is essential. In some instances the mangrove areas utilized for shrimp farms have only entered into shrimp production following abandonment of the sites by previous land use activities. Thus, in some cases, the original mangrove was cleared for fish farms or rice culture. The situation in Thailand involves a combination of the above circumstances.

The transfer of mangrove forest habitat to shrimp farming is a classical process of **land alienation**. The establishment of a shrimp farm may be rapid (i.e. direct replacement) or it may involve a gradual process which sees the mangrove area utilized sequentially for several different land uses prior to shrimp farming. The accumulated effects of these land uses prior to the shrimp farm, also degrade the mangrove habitat. The land alienation increases as coastal mangroves are gradually appropriated from their once complex ecological function in a multi-use capacity, and replaced by a single purpose, dominant, land use that subsequently limits all others.

The data in Table 6.4 indicates the change in mangrove area in relation to the change in shrimp farm area for the various regions of Thailand. In provinces or regions where there is a strong correlation, the loss of mangrove area provides an indication of unsustainability. Where there is yet no strong correlation in Thailand the author notes that these areas have not yet been fully developed by the shrimp farming industry. These regions are the currently desired destinations for relocating shrimp farms and are threatened by shrimp farming expansion. The data in Table 6.4 is consistent with a continuing expansionist trend in shrimp farming to develop land previously in other uses. Other authors have identified similar trends in other locations globally (e.g. Columbia).

The total decrease in mangrove area from 1986 to 1992 for all regions of Thailand was 20,322 ha. The total increase in shrimp farm area for the same period was 27,427 (Table 6.4). The central region has experienced a decrease in area devoted to shrimp culture (i.e. the crash) while shrimp farm area has increased in all other regions of

¹ Any change in the mangrove habitat different from its natural state would decrease the viability. In many cases the establishing of shrimp farms alters hydrological flow on the edge of mangrove and therefore ultimately effects the viability of what remains. In this case there is a gradual 'erosion' of the mangrove habitat. For example, wood cutting in the fringe or clearing of mangrove for access to the shrimp farm by roads or construction of drainage canals.

Thailand and mangrove area continues to decrease. The apparent 'growth' or increase in mangrove area for the western south is due in part to the reclassification of mangrove areas introduced during the time period (similar argument for the central region).

Despite the growth in mangrove area, the increase in shrimp culture area by 1,807 ha has can be attributed to a direct loss of mangrove.

Table 6.4 Change in shrimp farm and mangrove area (ha) in Thailand during the period 1986 to 1989 and 1989 to 1992

Province and region	Change in shrimp farm area 1986-1989	Change in mangrove area 1986-1989	Change in shrimp farm area 1989-1992	Change in mangrove area 1989-1992	Mangrove area in 1992	Percent of total (%)
Central	+11,167	-420	-16,149	+837	1,433	0.81
Samut Prakan	+693	-103	-1,640	+122	122	0.07
Bangkok	+683	NA	-1,273	NA	NA	NA
Samut Sakhon	+4,637	-142	-4,865	+109	109	0.06
Samut	+2,289	-49	-5,935	+497	497	0.28
Songkhram						
Phetchaburi	+2,471	-88	-2,058	+146	635	0.36
Prachuab	+396	-38	-378	-37	70	0.04
Khiri Khan						
Eastern	+10,740	-7,272	+5,390	-10,092	10,617	6.03
Chanthaburi	+8,530	-5,811	+3,632	-5,987	2,709	1.54
Rayong	+968	-660	+504	-1,604	154	0.09
Eastern South	+8,119	-2,560	+5,820	-3,432	13,652	7.75
Chumphon	+945	-1,361	+750	-763	1,502	0.85
Surat Thani	+4,475	-517	+1,355	-1,279	2,488	1.41
Western South	+533	-5,626	+1,807	+8,243	150,413	85.41
Phangnga	+116	-794	+400	-667	34,959	19.85
Phuket	+153	-149	+95	-295	1,491	0.85
Ranong	+128	-424	+177	-1,636	19,546	11.10
Total	+30,559	-15,878	-3,132	-4,444	176,115	100.00

Notes: 1. Mangrove data: Royal Forest Department in 1991-1992 from NRCT, 1994

2. Shrimp farm data: Fishery Policy and Planning Division, DOF, 1994

3. 1992 is the most recent year for any mangrove or shrimp farm data with the exception of production statistics reported in trade journals.

4. Assessment of mangrove area has not always used the same methods. For example, remote sensing is now exclusively used to determine mangrove area.

Figure 25 illustrates the 1993 land use in Thailand's Chanthaburi province.² This figure demonstrates the level of appropriation by shrimp farms in the once mangrove forested coastal area. Previously, mangroves were the dominant feature of the Chanthaburi coastal zone. Mangrove loss and shrimp farm expansion in Chanthaburi is a good opportunity for the application of this key indicator.

² Land use classification map of in the Chanthaburi coastal zone from SPOT 93.

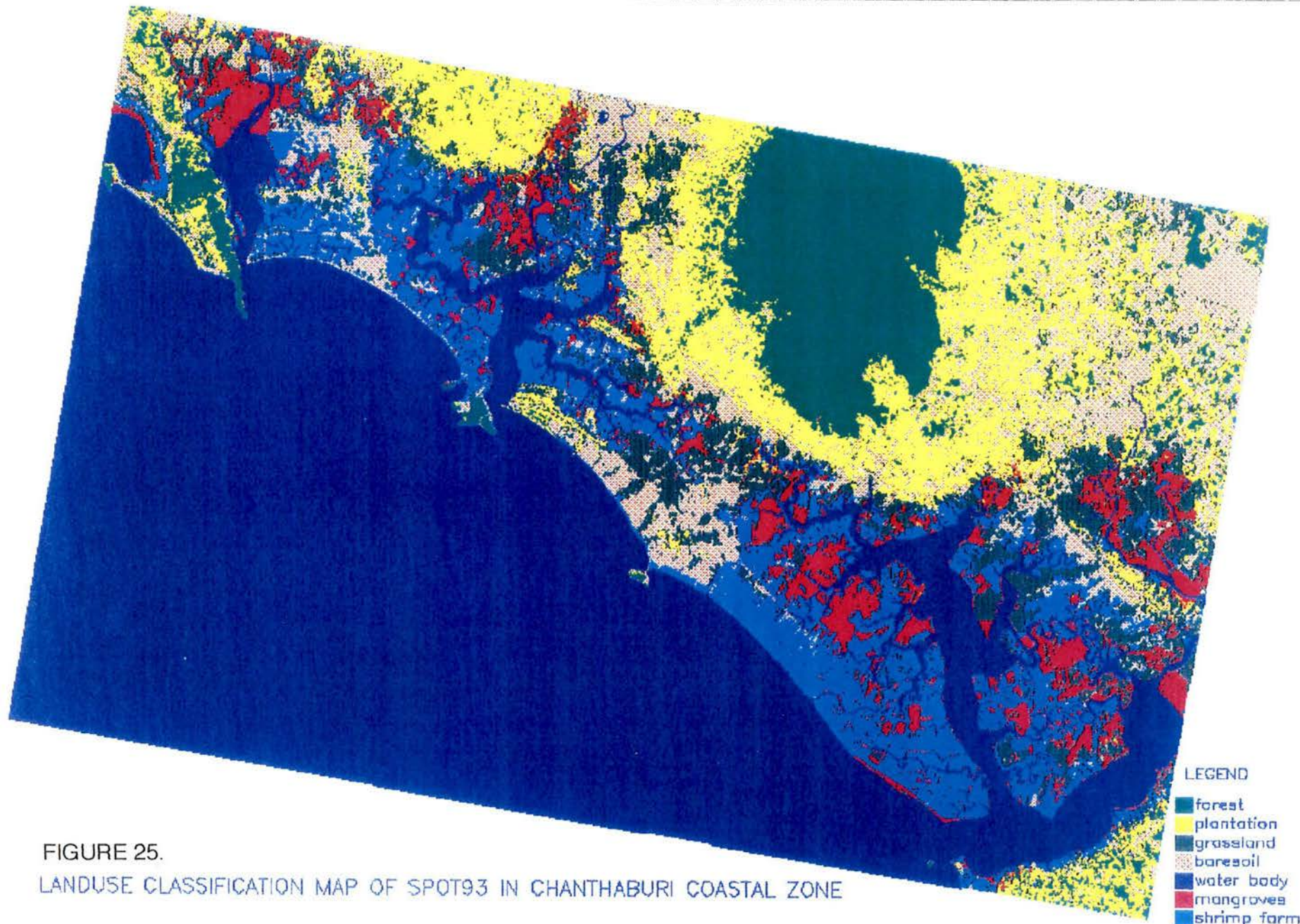


FIGURE 25.

LANDUSE CLASSIFICATION MAP OF SPOT93 IN CHANTHABURI COASTAL ZONE

In Thailand, the construction of shrimp farms has caused the destruction of large tracts of mangrove forest. Fish and shrimp ponds that establish operations in these ex-mangrove areas eventually experience the above mentioned environmental impacts making re-establishment of the natural ecosystem difficult. Ironically, the excessive clearing of mangroves for aquaculture (also for fuel wood and timber) has caused serious losses in the nurturing of commercially important finfish and crustaceans. Thailand has lost a total of 191,785 ha of mangroves since 1961. This is a 48 % reduction from the original figure of 367,900 ha in 1961 to just 176,115 ha in 1992 (NRCT, 1994). This latter figure comprises just 0.3 % of the total land area. This reduction includes approximately 10,000 ha of pristine forest lost, in the last 10 years, to the growing intensive shrimp culture industry (Anon., 1993d; Vibulsreth and Aschbacher, 1992), and a total of 65,000 ha altogether from the initial use of mangroves for logging or traditional extensive culture which has subsequently intensified (Phillips et al., 1993; Pullin, 1993). In 1989 the total mangrove area in Thailand was only 180,559 ha, of which more than 19,200 ha were classified as deteriorated mangrove forest. The annual rate of loss (about 12,982 ha/yr) was highest during the period 1979 to 1986 during which 38,000 ha of mangrove forests were removed (Phillips et al., 1993). In general, about 64 % of the mangrove area has been exploited for aquaculture³.

There are some reasons for the demise of Thailand's mangrove ecosystems. For example, in the construction of Thailand's shrimp farms, few operators reserve a strip of mangrove along the shoreline to serve as a natural buffer zone. This feature leaves virtually no natural habitat within farm boundaries. Typically farms are side by side and so no habitat is left between them. In a typical area, with a high density of intensive shrimp farms, no vegetation is visible. The outside investors to shrimp farming, who do not have intimate contact with these ecosystems, do not perceive their true sustainable value, and construct new shrimp ponds regardless of the loss of the mangroves. When these ponds begin to lose production, the farmers move to new mangrove areas thus perpetuating the vicious cycle. Replacement of mangrove habitat by shrimp culture transforms a multi-user/use coastal resource into a privately-owned, single purpose (and often unsustainable) business (Pollnac, 1992).

Thailand's Sam Roi Yot National park is an unfortunate example of habitat loss and encroachment attributed to the expansion of shrimp farming. Much of the park has been

³ On a province by province basis the removal of mangroves for aquaculture differs significantly.

invaded by shrimp farmers to the point that it can no longer be considered a viable wetland habitat. The vista from the surrounding hills include the hundreds of shrimp ponds, some of which are now abandoned. The shrimp farmers are not legally entitled to the land, feel even less responsible for its condition, and quickly vacate the site when the shrimp operation fails. Thailand is not unique and similar events are taking place in other areas of the world. In Indonesia, most of the 300,000 ha of land being cultured for shrimp in 1991 was ex-mangrove land with "plans" to develop more than 1 million ha to shrimp ponds (Newkirk, 1991). However, signs of government recognition of the problems are emerging. In 1995 the Cambodian government temporarily banned licenses for new shrimp farms, claiming that the industry was responsible for destroying about 75 % of the mangrove forest in the Koh Kong and Sre Ambel areas. The shrimp farming and charcoal industries were accused of reducing the mangrove forests by as much as 63,000 ha over the last two years (Naga, *The ICLARM Quarterly*, 1995). Severe habitat loss to aquaculture has highlighted the importance of habitat protection; unfortunately belated in many cases. Thailand is taking steps to address the conservation and protection issues surrounding mangroves. There are discrepancies between figures reported by the DOF and the RFD figures, making it difficult to be definitive on the subject of mangrove removal.

Table 6.5 compares the loss of mangrove compared to the increase in shrimp farming area for the province of Samut Sakhon. This information demonstrates the rapid decline in mangrove forest area and the matching increase in shrimp farm area. For Samut Sakhon, the previous land uses prior to the development of intensive shrimp farming were 39.0 % mangrove (37.1 % salt pond; shrimp pond 20.5 %; and coconut plantation 3.4 %) (OEPP, 1994b). Thus the majority of mangrove loss can be attributed to intensive farm expansion. For this province, it must be emphasized that there have been many changes in land use and that the intensive shrimp farms are a recent phenomenon. This area, as previously highlighted, was an early salt farming region that converted to shrimp culture methods when intensive farming was introduced. Originally, all of the previous provincial coastal land was mangrove. It was the speed at which transfer occurred which was most relevant to this province. Similarly, this is the case for mangrove areas which are currently being converted to intensive methods. The removal of the original mangrove habitat in Chanthaburi province followed by the direct occupation by shrimp farms is a better illustration of this indicator (Tookwinas and Leeruksakiat, 1994).

Table 6.5 Comparison of mangrove area and shrimp farm area for Samut Sakhon province for various years

Samut Sakhon	1975	1979	1986	1989	1991	1992
Mangrove area (ha)	18,500	14,416	142	0	0	109
Shrimp farm area (ha)	2,590	6,567	7,623	12,260	8,189	7,395

Mangrove data: Royal Forest Department in 1991-1992 from NRCT, 1994

Shrimp farm data: Fishery Policy and Planning Division, DOF, 1994b

Application of this key environmental indicator to other shrimp farming countries in which mangroves are threatened by shrimp farm development would be most appropriate for Columbia, Ecuador, Cambodia, Vietnam Indonesia, and India. Previous investigations of mangrove destruction in Ecuador resulting from mariculture development have been reported by Parks and Bonifaz (1994) who examined the non sustainable use of mangroves for mariculture and by Terchunian et al. (1986) who utilized mangrove mapping to demonstrate the impacts of shrimp pond construction in Ecuador.

Mangroves are halophytic (salt-tolerant), seed bearing, woody plants of which there are more than 50 species in Asia (ADB, 1991). With increasing population and economic growth in the coastal zone, mangroves (wetlands) are under pressure worldwide from many land use demands. In Southeast Asia and Central America, large tracts of mangroves have been lost to shrimp farm development. When requisitioned for shrimp farms mangroves are cleared and the once balanced and highly productive ecosystems disrupted. Such habitat destruction and alienation of land is the most serious and potentially irreversible ecological impact of the industry. This loss is tragic because these ecosystems (like most wetlands) provide a variety of significant environmental goods and services that sustain social and economic structures and activities (Singh, 1987; Csavas, 1988; Folke and Kautsky, 1992). Wetland habitat destruction has become one of the globally recognized trademarks of the intensive shrimp farming industry. The characteristically invasive, aggressive and opportunistic tactics employed by shrimp farming entrepreneurs has enabled them to capitalize on the overall lax enforcement and protection of designated lands and have outpaced conservation or preservation measures.⁴ This trend of mangrove removal that destroys the inherent

⁴ In Thailand, many believe that the destruction was permitted by the vagueness and contradictions in the legislation on mangrove forests, which potential users and some administrative authorities interpreted in their own favor. From 1978 to 1987, no less than six decrees were issued by the Thai Council of Ministers, showing concern, but also indecision, and resulted in heightening difficulties in drawing up a national policy without ambiguities.

natural systems, as described by several authors (e.g. Primavera, 1991; Sanit, 1993), has severe ecological, economic and social impacts (Table 6.6).⁵ These findings are further supported by Wolanski (1992) in a report on the hydrodynamics of mangrove swamps and their coastal waters. These impacts affect the sustainability of all coastal activities and are described in detail below.

Table 6.6 Environmental factors effected by mangrove degradation (Sanit, 1993)

Physio-chemical: water temperature, DO, nutrients, salinity balance, hydrology, sedimentation, turbidity, toxic substances and soil erosion.
Biological: changes in dominant species, population density and structure of the plant and animal communities.
Ecological balance: regeneration, growth habitat, food chains, both of the mangrove ecosystem and the neighboring ecosystem.

The harmful consequences of clearing the mangrove forest, include: development of acid-sulfate soil conditions, water-logging and rise in salinity and temperature of the water, due to exposure of the cleared land to oxygen and sunlight. Research conducted by Hong (1993) determined the environmental impacts of mangrove deforestation in the Mekong delta of Vietnam and included the following impacts: increased coastal erosion, salinity intrusion, declining shrimp PL abundance, declining abundance of the commercially important mangrove mud crab (*Scylla serrata*), declining shrimp pond yields resulting from the acidification of pond waters/soils and various public health impacts.⁶ These findings are supported by previous studies confirming that mangrove removal may cause coastal erosion (Carter, 1959), changes in patterns of sedimentation and shoreline configuration (Snedaker and Getter, 1985), or make coastal areas more vulnerable to storm damage. These significant adverse effects have prompted many studies on the conversion of mangrove areas into aquaculture sites and their impact (Saenger et al., 1983; Hamilton and Snedaker, 1984; Naamin, 1986; Camacho, 1986). Relevant Thai reports with similar findings have been reported by OEPP (1994b) and Briggs and Funge-Smith (1994) for Chanthaburi province and the Pak Phanang region of Southern Thailand respectively.

⁵ Ultimately, in addition to ecological impacts, mangrove conversion leads to land use conflict between shrimp and fish operations and other coastal dwellers which is even more pronounced when the impacts spread outside the farm to nearby land and water resources.

⁶ Increased malarial incidence in coastal areas linked to the increased number of stagnant pools of breeding mosquitoes.

Typically, environmental damage to mangroves occurs when the importance of the land to other users is overlooked (Rosenthal, 1994). Quite often habitat is destroyed for aquaculture with insufficient attention to other users. Factors such as forest abundance, soil and water quality and the carrying capacity of the coastal mangrove swamps are some of the typically overlooked aspects⁷. The effects on biodiversity in all its dimensions (species, populations, community) are clear.

6.6.2 Key indicator #2: environmental (land salinization and land subsidence)

The lack of overall planning in shrimp farm construction leads to excessive removal of freshwater from underground aquifers causing salt water intrusion. Agricultural production is impaired, directly conflicting with other land and water users. In Thailand, Taiwan, and the Philippines intensive shrimp farm expansion has resulted in salt water intrusion and salinization of freshwater aquifers public canals and the degradation of soils, potable and agricultural water supplies (Jayasinghe and De Silva, 1990; Primavera, 1991; PSU, 1991; Liao, 1992).⁸

The full extent of saline intrusion in Thailand is not known. Salinization of agricultural land due to shrimp farm expansion has been reported from several provinces.⁹ A survey of two districts (Koh Kwang and Chang Kham) in the province of Chanthaburi showed that 16 to 22 % of agricultural farms were affected by saline intrusion linked to shrimp pond expansion. A remote sensing study carried out in 1993 for two provinces in southern Thailand showed that 3,344 ha of shrimp ponds had led to the salinization of 1,168 ha of agricultural land, mostly rice fields (OEPP, 1994a). Thai (1992) reported changes in productivity for rice farms operating in two districts of Nakhon Si Thammarat province. Salinity intrusion resulting from shrimp farming may lead to further devaluation of marginal agricultural land and social conflict (Jayasinghe and De Silva, 1990).

⁷ Coastal wetlands especially mangroves are complex ecosystems. They represent an intermediate phase between terrestrial and aquatic environments and are sensitive to changes in hydraulic conditions.

⁸ Irrigation canals to bring saltwater inland have altered saline control barriers in many locations to accommodate shrimp farms.

⁹ The extent of salinity intrusion caused by shrimp farming is unknown. While shrimp farming may have accelerated soil salinization, it cannot be held totally responsible and the perception that shrimp farming has been the major contributor to soil salinization is unwarranted. Agriculture irrigation has been the major component and the FAO has estimated that at least 50 % of the world's irrigated land suffers from salinization (White, 1977).

Salinization and land subsidence are major causes of social conflicts with local farmers and other residents. In 1991, a dispute between shrimp farmers and rice farmers in southern Thailand resulted in the death of a shrimp farmer over damages from shrimp farm effluent to paddy fields (Anon., 1991). Rice farmers have continuously protested and demanded compensation from shrimp farmers for salinization. In some cases rice farmers have received death threats. There is little government intervention in the conflicts. New (1991) has reported that the price for the life of a protesting rice farmer is said to be just 20 kilograms of shrimp.

The salinization process is particularly relevant to the Upper Gulf region including Samut Sakhon province where increasing numbers of operations are being established inland using low salinity culture methods. This trend was observed in Samut Sakhon Amphoe Ban Phaeo wherein relocation of intensive culture operations have established shrimp farms inland and carried on with 'business as usual'.

These inland operations use available freshwater canals to supply water to the culture ponds and for the discharge of pond effluent (normal water exchange and harvest discharge). These low salinity operations achieve brackish water in the culture ponds the freshwater supply is supplemented by hyper saline salt pan effluent (around 200 ppt) purchased from local salt farms. The environmental (and economic) impact of these practices create potentially irreversible future problems.

Deliberate salinization of inland fresh water sources and land areas cannot be justified. The potential for conflict over these issues is increasing in the Upper Gulf region. Salinization from these inland operations is likely to have significant negative environmental consequences for the surrounding freshwater and soils of the watersheds. The practice of locating inland suggests that these operations are unsustainable. The increase in popularity of locating inland and using low salinity operations will represent a future trend in Thailand as available sea water coastal sources are increasingly found to possess high levels of pollutants and thus are less desired sources for shrimp farming operations. Application of this indicator is limited by a lack of information specifically identifying intensive farm development as the causal factor. Most studies have focused on the salinization effects of agriculture irrigation.

Shrimp farm construction affects the natural hydrological flow patterns of underground waters causing land subsidence and salt water intrusion. Coastal land subsidence resulting from the extraction of freshwater from underground aquifers for shrimp farming has been reported in the Philippines (Primavera, 1989) and Taiwan (Chiang and Lee, 1986). There is little recorded information on subsidence which can be directly attributed to shrimp farming. Problems associated with land subsidence include flooding, salinity intrusion and insufficient supply. To make freshwater available in areas where there are insufficient surface supplies wells have been drilled to access aquifers. Early farming techniques made extensive use of freshwater to dilute saline culture ponds and are suspected of contributing to land subsidence. For comparison, aquifer supplies, utilized for intensive eel farming operations in Taiwan caused severe cases of land subsidence of up to 1 meter.

Shrimp farming in Thailand is not viewed as a major contributor to land subsidence in comparison to ground water extraction for other uses. However, any impacts related to excessive ground water extraction are severe, long-term and potentially irreversible.

6.6.3 Key indicator #3: environmental (water quality degradation and nutrient and organic enrichment of coastal waters)

The key indicator of water quality has been selected on the basis of a characterization of shrimp farm discharge as a contributor to water quality degradation and nutrient enrichment. The connections between farm effluents and environmental concerns have been drawn (Boyd and Musig, 1992; Pruder, 1992). However, there are no studies that characterize the receiving waters of shrimp farm discharge or correlate water quality to farming activity. There is a high degree of variability in data recorded from various shrimp farming operations and the variation in data makes comparison to other operations difficult.

The discharge of effluent water, pond sludge, and pond cleaning water, high in nutrients, high in organic matter and low in dissolved oxygen and alludes to the risk of eutrophication and hypernutrification. This risk is increased given the geographical constraints of the irrigation canals and near shore receiving waters of the Upper Gulf region. These discharges include the water released during rearing to control the quality

of water in the ponds and water discharged during harvesting or during pond preparation before a new crop (OEPP, 1994a).

The intensive shrimp pond data (Table 5.2) are particularly important. Effluent discharged without treatment contributes directly to nutrient levels and recycles contaminants to the surrounding water ways. As the data in Table 5.2 shows, field sampling confirms elevated levels of nitrogen and phosphorus in intensive pond water. Field data values of Total N and Total P from this study (Table 5.2) were 0.7246 ± 0.6862 mg/L and 0.3711 ± 0.7251 mg/L respectively. These values lie within the range of reported literature values of shrimp pond effluent concentrations (Table 6.7). To a lesser extent, the semi-intensive and extensive ponds, which also recirculate without treatment, add to the loadings of the canals and surface waters of the surrounding area. The loading of the ecosystem is defined as the pond and surroundings.

Table 6.7 presents a comparison of the effluent concentration (mg/L) from an operating shrimp farm effluent with other types of wastewater. Although the magnitude of the parameters are much less than other effluent streams, the significance of shrimp farm effluent comes from the high volumes of low concentration effluent and concentrated releases during harvest and the cleaning of shrimp ponds.

Table 6.7 Shrimp pond effluent concentrations (mg/L) during normal operation compared to other types of wastewater (OEPP, 1994a)

Parameter	Shrimp pond effluent	Domestic waste water			Fish processing plant effluent
		Untreated	Primary treatment	Biological treatment	
Reference	1	2	3	4	5
BOD	4.0-10.2	300	200	30	10,000-18,000
Total N	0.03-1.24	75	60	40	700-4 530
Total P	0.01-2.02	20	15	12	120-298
Solids	119-225	500	-	15	1 880-7 475

Notes: 1. Kanit et al., 1992; 2,3,4. Warrer-Hansen, 1992; 5. Sutam et al., 1991.

Shrimp farm discharge, particularly from intensive farms, has been characterized in Thailand (Table 6.8), Hawaii (Ziemann et al., 1992), and to a certain extent in other locations (Lin et al., 1993; Hopkins et al., 1993a, Hopkins et al., 1993b). Also, the quality of effluent water from 15 intensive shrimp culture ponds was monitored by Chaiyukum and Songsangjinda (1992). The results of this study are presented as comparative data in Appendix A.

Table 6.8 Effluent water quality recorded at an intensive shrimp farm in Thailand during a 5-month grow-out period (data from C. K. Lin, Asian Institute of Technology, Bangkok, Thailand)

Pond size (ha)	0.48-0.56
Pond depth (m)	1.5-1.8
Salinity (ppt)	10-35
Temperature (°C)	22-31
pH	7.5-8.9
Total phosphorus (mg/L)	0.05-0.4
Total nitrogen (mg/L)	0.50-3.4
Total ammonia (mg/L)	0.05-0.65
Dissolved oxygen (mg/L)	4.0-7.5
Chlorophyll a (mg/L)	20-250
Total suspended solids (mg/L)	30-190
Water exchange frequency (%/day)	5-40

Any characterization of shrimp pond effluent must mention the harvest situation. Table 6.9 represents the quality of effluent during the final stages of harvesting and cleaning of ponds and shows extremely high concentrations of both nutrients and organic matter. The loadings at this time are substantially greater than the loadings incurred during the culture period because of discharge of material previously bound to sediment particulate matter. Impacts on the receiving waters are likely to be most significant at this time.

Table 6.9 Effluent quality during cleaning of four intensive shrimp ponds in Thailand (data from C.K. Lin, Asian Institute of Technology, Bangkok)

Total N (mg/L)	2600	1900	2400	2600
Total P (mg/L)	110	60	40	70
Organic carbon (%)	13.6	7.3	10.4	13.7

Two additional factors need to be considered to obtain a measure of the total water quality of the shrimp pond and coastal waters. These are the levels of heavy metals and persistent organic pollutants and nutrient enrichment by sediment loading (wet and dry sediment).

The data in Table 5.6 confirmed the presence of heavy metals in all of the water sources of the case study region (i.e. the canals, coastal water supplies and shrimp ponds). This was similarly confirmed for persistent organic pollutants (Table 5.5). The data suggests that once these contaminants are introduced they are continuously recycled within the farm system with little opportunity for escape. Farm practices ensure this is the case, as pond sediments are continuously disturbed during grow-out, though aeration and water

exchange. These practices reduce the time available for contaminants to find a pathway out of the pond environment through accumulation and assimilation in the wet sediment. In addition, any that does accumulate, is removed as dry sediment after harvest and distributed to the pond dikes and farm area where they may leach back to the pond water. Also, these substances may accumulate in the wet sediments of the canals external to the farm are remobilized when the canals are dredged to improve water supply to the shrimp farms. The source of contaminants is continuous and will in all likelihood, increase, with the concurrent increase in industrial and agricultural activity. Therefore, these substances will remain in all of the shrimp ponds of the case study region and in the surrounding ecosystem. The trends over time of the persistent organic contaminants (DDE, dieldrin, heptachlor) should be monitored as a component of the indicator.

Other important components of the sediment significantly degrade the total water quality. The accumulation of sediment, both wet and dry, resulting from intensive shrimp culture alters the total water quality of the internal pond environment, where it is almost always monitored and controlled, and the receiving environment, where it is almost never monitored. Farmers are generally focused on the internal influence of these sediments, but have been increasingly reminded of the problems resulting from accumulation of sediment in the receiving environment. Repeated discharge of wet sediment (high in N and P) leads to a condition where accumulated wastes are returned and may also increase the likelihood of eutrophication and hypereutrophication. The high BOD sediment competes for available oxygen and stresses the shrimp. This is generally rectified by water exchange and discharge of this high BOD sediment.

In addition the high N and P content of discharge effluent increases the likelihood of eutrophication or hypereutrophication in the receiving environment. The repeated discharge to restricted water supplies decreases the water quality available to the shrimp farmer. Such adverse effects are most pronounced during a shrimp harvest. However, this condition is continuous and negatively affects shrimp farm performance once the assimilative capacity of the receiving environment is exceeded. The limited capacity of the canals combined with poor tidal flushing hastens this condition. A more detailed analysis of wet and dry sediment in order to determine overall water quality.

There is a direct relationship between the culture intensity and waste production from intensive shrimp farms. This was demonstrated by the results of a wet sediment and

water quality study in southern Thailand which indicated that increasing the stocking density by 74 % increased the waste loading to the environment by 86 % (to 907 kg/ha/cycle) N and 35 % (to 320 kg/ha/cycle) P (Boyd, 1992).¹⁰ Waste production of this magnitude was a contributing factor to the failure of Upper Gulf shrimp farms by self pollution from effluent contamination. The total BOD wet sediment discharged from all Thai shrimp farming operations has been estimated to be as high as 35,000 MT/yr (Briggs and Funge-Smith, 1994b).

The amount of dry sediment produced by a single pond can be quite large. The average sediment accumulation over the four month grow-out period in farms studied by NACA (1994) was 559.4 MT/ha/crop. Based on this amount, further calculations determined that the annual total sediment output of all farms in the two districts was 2.72 million MT/yr. Another study has estimated the total production of dry sediment for the Thai industry to be 16.2 million MT/yr (Briggs and Funge-Smith, 1994b).

The total loading is substantial when wet sediment (BOD) and dry sediment are added. The Thai industry clearly makes a substantial contribution to the waste loading of the coastal environment. Opportunities for improving sustainability through waste reduction methods in shrimp farming operations are discussed in the proposed solutions section below.

6.6.4 Key indicator #4: human and ecosystem health (impacts of farm chemicals on coastal ecosystems)

Aquaculture chemicals are a potential risk to ecosystems when improperly used (Ackefors et al., 1990; Barg, 1992). Improper application has resulted in contamination reducing both product quality and consumer acceptance of the shrimp. Reliance on chemicals can lead to drug-resistant pathogens, which may have serious negative feedback effects on farm productivity. The over use of chemicals may result in reduced fitness, poor growth and decreased survival rates during the grow-out phase. Pond soils may be degraded by excessive chemical treatment. The 'needs' for aquacultural chemicals for Penaeid (*Penaeus sp.*) shrimp species have been described (Williams and Lightner, 1988, Bell and Lightner, 1987) and for molluscs by Brown (1987). Though

¹⁰ For comparative purposes the human-equivalent daily waste production of N and P has been estimated by various authors (e.g. Mackay, 1990; Bergheim et al., 1982) to be 11 grams and 3 grams respectively.

needed, over prescription of chemicals leads to problems. Table 3.12 in Section 3.11 has presented the common chemicals used in penaeid hatcheries and grow-out operations.

Table 6.10 compares common chemicals with respect to usage and the associated 'environmental risk' (Phillips et al. 1990). Thai farmers generally do not consider the 'environmental risk' of chemicals. The decision to use chemicals is based on the crop value. Examples are the use of oxytetracycline and chloramphenicol which despite having medium and high 'environmental risks' respectively are used extensively.

Table 6.10 Common chemicals used in penaeid shrimp hatcheries and grow-out ponds (modified from Phillips et al. 1990)

Compound type	Use	Environmental risk
• Piscicides and molluscicides		
Tobacco dust (nicotine)	Limited	Low
Calcium hypochlorite	Extensive	Low
Teaseed cake (saponin); derris root extract (rotenone)	Extensive	Medium
• Organochlorines		
DDT, endrin, aldrin; organotin	Limited	High
• Disinfectants, water and soil treatment		
EDTA; sodium hypochlorite; benzalkonium chloride; zeolite	Extensive	Low
Potassium permanganate	Limited	Low
Copper sulfate	Extensive	High
• Chemotherapeutants		
Formalin	Extensive	Low
Methylene blue	Limited	Low
Oxytetracycline; malachite green	Extensive	Medium
Chloramphenicol	Extensive	High

A detailed description of oxytetracycline (OTC), and chloramphenicol, will be utilized to illustrate the selection of chemical treatment as a key indicator of the situation with respect to antibiotics. The persistence of OTC in sediments was studied by Jacobsen and Berglind (1988) who found that the spread of OTC in the marine environment increases resistant bacterial strains and the risk of transferring plasmids coding for resistance into human pathogens. The drug was found in concentrations capable of causing anti microbial effects up to 12 weeks after administration with detectable concentrations of OTC in the sediment three to six months following feeding of the antibiotic (Jacobsen and Berglind, 1988; Samuelsen, unpublished results cited in Samuelsen, 1989). Because of OTC's wide anti-bacterial spectrum and high potency it is extensively used in shrimp farming. Due to its poor absorption rate it must be applied

in high dosages to be effective. OTC and other chemicals used in aquaculture pose considerable environmental threats to shellfish and wild fish.

Residues of biological chemotherapeutants

A host of antibiotics used in intensive aquaculture lead to the occurrence of antibiotic residues in shrimp aquaculture products and has raised valid concerns for human health. The Codex Committee on Residues of Veterinary Drugs in Foods (CCRVDF) with the assistance of the Codex Committee on Fish and Veterinary Products (CCFFP) is drafting proposals for the control of drug residues in food and the use of veterinary drugs (Schnick, 1991). However, currently there are no regulations guiding application or drug residues in food. As a result, antibacterial agents, mostly oxolinic acid and OTC are used in shrimp culture operations without prescription. Exported shrimp are occasionally stringently examined for drug residues. There is virtually no testing of shrimp destined for domestic consumption. Table 6.11 presents the allowed level of antibiotic residues for shrimp exported to Japan, America and Australia. Concentrations are reported in parts per thousand (ppt). These standards are based on human health concerns. Toxicity and allergies to anti-microbial drug residues, e.g., penicillin, chloramphenicol, OTC and others, have been recognized (Huber, 1971; Anon. 1984).

Table 6.11 Level of antibiotic residue (ppt) in shrimp allowed by Japan, America and Australia (Aquatic Fauna, 1991)

Type of antibiotic	Japan	America	Australia
Tetracycline	0	0.5	-
Oxytetracycline	0	0.5	0.25
Chlortetracycline	0	0.05	0.05
Chloramphenicol	0	0	-
Penicillin	0	0.05	-
Tylosin	0	0.3	0.2
Monansin; bacitracin	0	-	-

In Thailand, oxolinic acid and oxytetracycline have been detected in *Penaeus monodon* tissues above acceptable levels by Saitanu et al. during a study from 1991 to 1992 (Table 6.12). The large number of cases in which drug residues were found in cultured shrimp in the open markets of Thailand reflect a failure of shrimp farm management. During testing in June 1992, 37 % of the samples tested positive.

Table 6.12 Incidence of antibiotic residues (mg/L) in *Penaeus monodon* (Saitanu et al., 1994)

Year and month	No. of samples	No. positive	Percent (%)
1990: October	50	13	26.0
November	141	8	5.7
December	97	7	7.2
1992: January	204	7	3.4
February	137	0	0
March	107	17	15.9
April	109	7	6.5
May	111	8	7.2
June	103	38	36.9
July	143	10	7.0
August	108	6	5.6
October	151	1	0.7
Total	1,461	122	8.4

6.6.5 Key indicator #5: socioeconomic (degree of intensification-production (MT), area cultured (ha) and number of farms per kilometer of coastline)

The rapid expansion of shrimp farming has resulted in very unrealistic production targets mirroring the expansionist policies of the region. These growth characteristics are indicative of a very unstable and unsustainable industry. Such characteristics can be illustrated in terms of various 'densities' (i.e. production in MT, number of farm units and culture area per kilometer of coastline). Given that the level of intensification is limited by the availability of land, water, labor, fry, food and fertilizers some staggering densities were achieved in the Upper Gulf of Thailand (Table's 6.13, 6.14, and 6.15). The trend from these indicators clearly indicates the rise and fall of shrimp farming in the Upper Gulf. Such statistics could only have been achieved through a high degree of biophysical resource exploitation and are appropriate for application to other shrimp farming regions in other jurisdictions. Information used to derive these indicators is generally readily available.¹¹

¹¹ Another application of production and area cultured data would be to calculate productivity declines in kg/ha experienced in shrimp farming regions. This information would indicate the harmful effects of shrimp aquaculture operations. The onset of productivity decline would suggest that a number of other events have preceded the event i.e. destruction of coastal mangrove habitat, decline of natural assimilative capacity for aquaculture effluent, breakdown of ecosystem support through repeated excessive inputs of intensive farm effluent.

Table 6.13 illustrates the 'production density' for the Upper Gulf provinces from 1987 to 1992.

Table 6.13 Shrimp 'production density' (MT/km) for Upper Gulf provinces from 1987 to 1992 (DOF, 1994b)

Province	Coastline (km)	1987	1988	1989	1990	1991	1992
Chonburi	156.80	0.94	0.98	1.87	2.91	8.65	6.03
Chachoengsao	12.20	63.77	232.29	236.64	653.93	400.00	806.89
Samut Prakan	47.20	83.35	65.55	134.15	89.89	62.80	25.04
Bangkok	0	1,395	1,577	1,102	1,312	827	652
Samut Sakhon	38.80	139.25	371.31	356.16	257.45	76.80	55.72
Samut Songkhram	21.20	167.36	581.74	521.04	375.33	109.39	45.71
Ratchaburi	0	0	0	0	0	0	0
Phetchaburi	90.60	4.58	14.93	61.52	48.54	37.60	31.49
Regional Value	366.80	42.59	97.47	111.92	99.06	51.07	50.73

Table 6.14 illustrates the 'culture area density' for the Upper Gulf provinces from 1987 to 1992.

Table 6.14 Shrimp 'culture area density' (ha/km) for Upper Gulf provinces from 1987 to 1992 (DOF, 1994b)

Province	Coastline (km)	1987	1988	1989	1990	1991	1992
Chonburi	156.80	3.76	4.25	4.21	4.02	4.32	3.18
Chachoengsao	12.20	146.39	141.61	131.92	269.11	256.00	222.58
Samut Prakan	47.20	153.71	160.83	162.07	128.81	133.81	128.21
Bangkok	0	4,372.3	4,178.1	4,363.8	3,603.4	3,234.1	3,117.1
Samut Sakhon	38.80	208.17	250.57	312.74	206.52	211.06	190.60
Samut Songkhram	21.20	345.86	283.99	335.48	181.94	125.17	123.23
Ratchaburi	0	0	0	0	0	0	0
Phetchaburi	90.60	29.92	20.90	46.27	31.99	37.64	26.96
Regional Value	366.80	87.58	87.02	102.84	77.35	75.26	67.70

Table 6.15 illustrates the 'farm density' for the Upper Gulf provinces from 1987 to 1992.

Table 6.15 Shrimp 'farm density' (farms/km) for Upper Gulf provinces from 1987 to 1992 (DOF, 1994b)

Province	Coastline (km)	1987	1988	1989	1990	1991	1992
Chonburi	156.80	0.51	0.77	0.78	0.78	0.87	0.74
Chachoengsao	12.20	24.02	25.08	25.66	88.36	64.59	141.31
Samut Prakan	47.20	25.55	35.52	32.52	25.66	26.33	23.75
Bangkok	0	811	975	983	631	571	544
Samut Sakhon	38.80	30.23	54.15	59.15	48.38	31.19	29.64
Samut	21.20	41.98	59.95	58.68	27.22	22.26	18.21
Songkhram							
Ratchaburi	0	3	3	0	0	0	0
Phetchaburi	90.60	3.09	6.87	6.84	5.28	7.08	3.37
Regional Value	366.80	12.91	32.66	19.38	16.29	13.80	14.62

The data presented in Table 6.13 to 6.15 illustrates the rapid increase in density with associated biophysical resource use in Samut Sakhon province. The level of shrimp farming exceeded the local carrying capacity to the extent that negative environmental impacts precipitated a production decline. In addition, resource use for farm operation can be viewed as impacting land area beyond the farm.

The current study did not quantitatively estimate such additional appropriated land use or carrying capacity. However, the key indicator should assemble data from both aspects re:

- (1) Direct land use in the region
- (2) Other resources needed to conduct the operation and the land (or marine environment) equivalents they represent.

The second factor has been described as an area equivalent indicator (See Chapter 1). The following discussion outlines areas of data acquisition to fully document the indicator. This section applies the concepts presented in Chapter 1.

An application demonstrating the concept of the ecological footprint of shrimp farms was advanced by Larsson et al. (1994). In essence, they practically applied the concept of appropriated carrying capacity, as defined by Rees (1994), to shrimp farming in

Columbia, South America.¹² The results show that a semi-intensive shrimp in Columbia farm needs a spatial ecosystem support (*ecological footprint*) that is 35 to 190 times larger than the surface area of the farm. A typical shrimp farm appropriates about 295 joules of ecological work for each joule of edible shrimp protein produced. The corresponding figure for industrial energy is 40:1. More than 80 % of the ecological primary production required to feed the shrimps is derived from external ecosystems. The results of this study were compared with similar estimates for other food production systems, particularly agricultural ones. The comparison indicated that shrimp farming ranks as one of the most resource-intensive food production systems, characterizing it as an ecologically unsustainable through-put system. Although beyond the scope of this thesis, future work will conduct a footprint analysis of Thai shrimp farms. Preliminary information based on field observations and farm surveys suggests that external biophysical inputs (primarily water, high quality by-catch for feed and shrimp seed) required to sustain Thai shrimp farming operations that the footprint of shrimp farms is very large.

Another indication of the large ecological footprint of shrimp farms is demonstrated by the use of high quality 'food grade' protein rich inputs for shrimp aquaculture. This protein is supplied from by-catch harvested by marine fisheries which is then processed into shrimp feed. The species chosen for mass production is dependent upon this high quality feed input. This practice is fundamentally flawed and unsustainable. Also, much of the feed input (80 %) ends up waste with only 20 % ultimately being incorporated as shrimp biomass (Primavera, 1994). Shrimp farming differs from most land-based animal farming systems which are based on the culture of omnivorous or herbivorous (ruminant) animal species, including poultry, ducks, pigs, sheep, rabbits, goats, beef and dairy cattle (Tacon, 1994).

Marine fisheries resources supply the protein for shrimp feed. Studies by marine biologists have shown that the demersal fish catch has exceeded the maximum sustainable yield (MSY) since 1973. The result of this fishing effort has been extensive damage to the sea bed and depletion of the sea grass beds from demersal fish trawlers (DOF, 1994c). Fishing beyond MSY has led to a decline in total catch and the size and number of species has changed. The average size of the individual fish has decreased

¹² Bill Rees from the University of British Columbia introduced the concept of Appropriated Carrying Capacity in a general conceptual sense. The actual application in a technical sense by Larsson et al. (1994) represents a further step in advancing the concept to practical application.

and catches often contain young fish which are included with non-marketable fish and are lost to the industry before growing to maturity. Despite the possibility of severe ecological consequences, and the fact that economically important species are decreasing, fishermen can ignore these factors and continue to fish as even the less desirable species can be manufactured into shrimp feed.

The shrimp industry is not the only culprit in such ecologically devastating practices. Examples from the salmon farming industry are also available. Folke (1988) conducted a calculation for caged salmon farming fish-food inputs. It was estimated that to support one tonne of harvested cage-farmed salmon required about 5.3 MT of fish, needing 1 km² surface area of primary production in the Baltic Sea or in the North Sea. The surface area of primary production corresponded to 40,000 to 50,000 times the surface area of the cages themselves. These examples are indicative of negative trends which directly link to the consumption of shrimp products to severe and long term ecological impacts.

6.7 Some proposed solutions: analysis of barriers and the opportunities for reversing trends

Some proposed solutions, provided by an analysis of the barriers, will be discussed below. The discussion is organized by first presenting an overview of the barrier. Following this, solutions are presented in these key areas. As the schematic model shows, both human well-being and ecosystem well-being need to be considered as co-equal in advancing solutions. The solutions generated by the analysis will be collected from their respective headings below and presented in Section 7.2 (Recommended changes in the institutional factors) of the final chapter.

6.7.1 The economic system

BARRIER

A common belief in Thailand, in keeping with economic systems elsewhere, is that economic growth alleviates poverty and provides funds necessary to reduce and conserve resources. This 'expansionist' or 'technological' world view influencing the economic system of Thailand has been readily applied to the shrimp farming industry. This world view is narrowly focused and fails to recognize that the depletion of biophysical resources to fuel consumption, both within and outside Thailand, leads to excessive degradation of the supporting ecosystems. The current economic system fails to recognize full costs and is subsidized by the environment.

The mentality of this economic system is directly applied to farming cycle operations with the belief that limits to production ,e.g. land and water availability, are very broad and may not yet be encountered. In this application, biophysical resources are valued only for their use as a raw material, and shortages of natural capital are thought to be substitutable with human-made capital using technology and innovation, within broad limits. Maintenance of this economic system fails to recognize full costs and that ecological limits are quite restrictive. This thesis has determined that Thailand must adopt alternative methods and mechanisms.

Recognition that the economic and environmental systems are inextricably linked and that the economic system is a subsystem of the ecological system was a starting point for the sustainability analysis. For Thailand, this has revealed that the destruction of coastal ecosystems has lead to the diminishing of the very resources with which the economic needs will have to be met in the future. National policies, although with the very best of intentions, have not achieved improvements in resource efficiency to offset the negative increases in the consumption of natural resources. Such policies are not exclusive to shrimp aquaculture but are indicative of the resource development mentality prevalent in most developing countries. However, the case of shrimp farming provides example of how the economic system has been applied to this commodity production with negative results. For example, the loss of mangrove habitat/natural areas (and all of their associated benefits versus the increase in shrimp farm area); the increasing

expansion of shrimp farming methods to other jurisdictions despite growing numbers of failed shrimp farms.

SOLUTIONS

The linkage between the economic system and the ecological system, termed the ecological world view, would incorporate ecosystem-based management for shrimp farming regions, and such practices as life-cycle design and best-management practices at the farm level. Adopting these ecologically oriented considerations in the shrimp industry will require a complete overhaul of current methods. The assessment of the past and present economic policies affecting the use of coastal resources in Thailand showed that these policies have accelerated the rate of degradation of coastal resources. The current situation not only demands the reorientation of economic policies, but also other related actions to attain sustainable development of coastal resources.

Revising macroeconomic policies

A review of selected macroeconomic policies operating in Thailand (Saisthi, 1989) which have the greatest impact on coastal resource use has revealed some potential areas where solutions may be implemented. Internally, government investment strategies promoting industry development need to be reviewed in terms of progress towards the sustainable use of coastal resources.

The government policy of negotiating with feed manufacturers to discount feed prices must be revised. The reduction of feed prices for the production of shrimp is ultimately passed on to the consumers and reflected in reduced shrimp prices. The shrimp are produced at less than the 'true' cost of production. This practice supports the increasing of fishing pressure on already overexploited stocks in near shore areas for feed production. This promotes further intensive aquaculture development that is wasteful of biophysical resources. Further, the promotion of increased domestic consumption and the expansion of overseas markets has proceeded without requirement for shrimp producers to improve production methods and increased the rate of coastal resource degradation. This promotes over consumption, or consumption without incorporating the full cost of production. Shrimp farmers have enjoyed this policy which allows for open access exploitation of coastal areas and shedding of all responsibility for payment of ecological costs. Both farm and shrimp processing industry development

has been promoted by the discounting of electricity costs for shrimp farmers and tax reductions on cold storage equipment. The above practices provide subsidy to consumption and to production and do not make the market show full costs.

Thailand's foreign economic policy has also encouraged heavy investment in aquaculture through tax credits and subsidized loans. This has encouraged international development assistance agencies, private sector investors and multinational corporations to invest in aquaculture infrastructure development.

These factors need to be reviewed to improve the rational use of coastal resources. External costs need to be internalized within the decision process of resource users. This will be viewed negatively by the shrimp farmers but may be made acceptable by carefully implemented procedures. Economic instruments and policies commonly utilized in other sectors may be useful. These instruments would promote a strengthening of policy mechanisms that rely on market forces to encourage environmentally-sound behavior. New environmental technologies and environmental services as part of the loaned assistance are required. Policies with sound scientific basis are advocated especially for renewable resources to optimize sustained benefits. The use of cost benefit analysis would assist agencies in identifying the true costs of coastal shrimp production.

Recommendation

- **Initiate studies on the macro-economic and social feasibility of intensive monoculture systems.**

Internalizing costs through application of full cost benefit analysis

What is the cost of producing one kg of shrimp? Is it the farm's private cost, estimated by various sources to be \$US 2.80 to 5.00/kg or more? In this research it was evident that these production costs are only a fraction of the 'real' cost and relate only the farm production cost of the farms. The social costs of externalities arising from shrimp farming have not been assessed. Costs of impairment, degradation and destruction to the ecosystem and environment as a result of shrimp farming are severe and in some cases irreparable. Unaccounted social costs must be considered if the shrimp industry is to improve sustainability. The author has found little or no evidence of such changes in Thailand. The density of farm operations and the level of intensification to increase

export suggests the contrary. Increased production is almost always viewed as a 'favorable condition'. The absence of cost benefit analysis that incorporates externalities is lacking in the industry. The solution to improving sustainability is a full application of cost benefit analysis. Constraints in application would be the assigning of economic value to socioeconomic costs. Examples of progress applying cost benefit analysis to the shrimp industry from other jurisdictions may assist Thailand (Khor, 1995).

India's state-run National Environmental and Engineering Research Institute (NEERI) recently reported on the effects of aquaculture using a cost-benefit approach (Khor, 1995). The main finding of this report was that the economic benefits of aquaculture in the Tamil Nadu, Andhra Pradesh, and Pondicherry areas are far outweighed by the ecological costs of the aquaculture projects. The damage costs from aquaculture have been determined to outweigh the benefits by as much as 4 to 1! This report has now prompted the Supreme Court to rule that the aquaculture industry in India should be reviewed. The application of full cost benefit analysis to all Thai shrimp operations is urgently required and might be first introduced as prerequisites prior to receiving loan assistance for aquaculture development.

Recommendation

- **Apply full cost-benefit analysis to all aquaculture developments to incorporate ecological and ecological externalities (i.e. pay full environmental costs)**

Domestic versus export consumption

Consumers in other jurisdictions continue to demand shrimp products. Industry assessment indicates that because of the high value of shrimp crops they are produced primarily for the export markets of Japan, Europe, and the USA (Filose, 1995). Shrimp, which had previously been produced in extensive systems and sold locally, are now cultured intensively and marketed globally. The practice of exporting shrimp to consuming countries from producing developing country is now the standard practice.

Commercial, intensive aquaculture operations enjoy the fact that shrimp are a fashionable and expensive cuisine item that command a high price. Resources must be allocated differently for the production of agro- and aqua- based commodities to meet

the needs of domestic markets and lessen the export to foreign markets. This export reorientation would improve food allocation to local consumers.

Recommendations

- **Improve the food allocation to local consumers by export reorientation**
- **Improve resource allocation for agro- and aqua- based commodities**
- **Inform and educate consumers as to the level of biophysical resource appropriation (and the resulting environmental impacts) required to support the shrimp farming effort. There is a large ecological deficit.**

Improving the performance of aquaculture investments

Current economic policies support rapid shrimp farm development which exploit biophysical resources to achieve excessive production targets. The increasing consumption of shrimp products and the availability of 'seed' money loans provides incentive for this behavior. Proposals requesting financial assistance highlight the potential of aquaculture to increase protein production for the rural peoples. Supported by national policies, shrimp farming operations have been established by commercial companies funded technically or financially by loans from international agencies.

These developments have been able to operate without consideration for environmental concerns. For example, the concentration of shrimp farming effort in the Upper Gulf that resulted in very high farm density and high production (and high profit in the short term!) then suffered collapse. Investment loans for this infrastructure development did not account for the negative consequences of environmental degradation. The Upper Gulf region provides an extreme example of the requirement to establish realistic production targets to meet longer term economic success. Several regions in Thailand now face such a dilemma and should heed the lessons provided by the Upper Gulf.

Recommendation

- **Reduce the rate and concentration of investment capital**

Increasing the accountability of lending institutions

The responsibility of improving shrimp farm sustainability also befalls lending institutions. Negative environmental consequences have resulted from both the rate of investment and investment management. The World Bank and Asian Development Bank inputs to this industry illustrate a concentration of **investment capital** that has ultimately resulted in the appropriation of significant **natural capital** (Anon., 1994e). Consumers of shrimp products are unaware of the level of biophysical resource appropriation required to support the shrimp farming effort and the resulting **ecological deficit**. These conditions have been supported by the Thai economic system and are accentuated by the global economic system. Solutions require agencies financially supporting development to change lending practices (Anon., 1994g) and control the rate and amount of investment (Anon., 1994e). The establishing of loan covenants to limit environmental degradation and the education of consumers are some key areas to improve the accountability of lending institutions.

Lending institutions have initiated some changes in lending practices (Anon., 1994e,g). In 1989, a WB report on the Philippines addressed the "extent and rate of degradation of natural resource stocks" which was then followed up with a report on the global shrimp industry. It was discovered that the sector had seen "dramatic increases in production and exports from developing countries". This is not surprising given the amount of investment into land-based shrimp production. The WB has now acknowledged that these dramatic increases have not come without associated environmental, socio-economic and economic problems. They have realized that the rapid expansion has led to a range of events which are highlighted by spectacular crashes in the industry (e.g. Taiwan 1988; Upper Gulf of Thailand 1990 to 1991), imbalances in the local food and labor economies and the severe ecological problems examined in this thesis. In 1991, the WB began to focus on "technologically advanced semi-intensive shrimp culture" compared to 'traditional extensive culture' and to support "an increase in cross-frontier cooperation in research".

In summary, although these initiatives are seen as positive developments there is currently no sign of decline in total assistance for shrimp culture development by the major lending institutions. However, it is apparent that the focus of investment and loans has taken on some new directions to examine specific research needs and

improvement in management practices. Further development of these approaches will contribute to the solution.

Recommendation

- **Increase the accountability of lending institutions and improve the focus of investment**

6.7.2 Science and technological innovation

BARRIER

This barrier has been established by the “mainstream view” that science and technology increase resource use efficiency. In the case of shrimp farming, the application of science and technology has increased resource exploitation and appropriation through intensification, allowed for rapid expansion in Thailand, and now globally through the distribution of intensive techniques based on the early Taiwanese model. These driving factors of the current industry have been nationally supported.

The increased access to, and development of, biophysical resources has created numerous on-site farm impacts, regional ecosystem degradation resulting in the failure of entire shrimp farming regions. Increasing numbers of such events have created a widespread socioeconomic impact. The increasing land alienation resulting from the establishing of intensive shrimp farms has created permanent and irreversible damage to the ecosystem while eliminating other productive land uses. Eventually, the land cannot even support shrimp culture and once shrimp culture has collapsed, conversion of land to other forms of agriculture or other land uses is made impractical by salinization.

Lack of research on pond dynamics and ecologically sound production systems

The majority of recent research efforts with respect to coastal shrimp aquaculture have been directed at maximizing pond- and farm-production levels, with an economic priority. This focus has been supported at the national level to increase export earnings, and by shrimp farmers wishing to increase pond productivity for higher revenues. It has been estimated by NACA that as much as 95 % of the research efforts in Thailand have emphasized increasing production. Few research efforts have focused on other

important issues of resource recovery and the recycling of waste metabolites from shrimp farming operations. Neglecting these research areas has been detrimental to the industry. Following the crash of Thai operations few shrimp farm operators were in a position to implement new sustainable practices and reverse degradation. Many of these important aspects of shrimp farming operations had not been adequately modeled by research. As a result, it has been difficult to evaluate different pond designs, equipment choices and management procedures required to improve the sustainability of farming operations.

Misapplication of shrimp farming technology

The wide application of shrimp farming technology can be likened to intensive production systems utilized to produce other agricultural commodities such as cotton. Historically, the production of cash commodities often results in yield being the primary goal with little regard for long-term sustainability of cash cropping practices (Folke and Kautsky, 1992). In tropical countries such as Thailand this is typified by intensive shrimp culture operations and emphasizes the narrow vision that has typically been used to assess the sustainability of high volume food production. The existing large areas of abandoned and derelict shrimp farm areas in Thailand highlight the need for fundamental changes to existing production methods and demand the introduction of ecologically sound methods. Solutions to this misapplication of science and technological innovation will now be proposed.

SOLUTIONS

Beginning at the farm level the case can be made for rethinking shrimp pond management in a most fundamental way. To assist the shrimp farmers, researchers must broaden their horizons and consider that some of the pond monitoring and treatment tools, considered innovative today, have in reality been long established practices. Answers to questions can be sought from a variety of available mariculture literature. Table 6.16 describes the farm operation considerations identified by Clifford III (1992) that, if acted on, would improve sustainability.

Table 6.16 Farm operations that must be better managed to improve sustainability (Modified from Clifford III, 1992)

-
1. Pond bottom condition and preparation; predator eradication
 2. Filtration of water (influent and effluent)
 3. Fertilization and phytoplankton bloom control
 4. Larval shrimp quality, handling, acclimation, and stocking
 5. Water exchange, aeration (optional), and monitoring and control of the key hydrological parameters
 6. Feed quality and management; feeding and pond fertilization
 7. Disease prevention
 8. Harvesting and product handling
 9. Cost management
 10. Optimizing stocking density
 11. Control of chemical use
 12. Treatment Systems (physical, biological, integrated culture, mangroves)

Control of chemical use

Shrimp farmers in all regions of Thailand continue to use non-registered chemicals in all aspects of farm operation. These practices are indicative of the inherent problem of the faith in chemicals and the resulting over prescription of these potentially harmful substance without due diligence. Education of the shrimp farmers that the majority of problems in the culture ponds can be overcome by reducing the chronic stressors is essential. The best demonstrated treatment for any disease is prevention, and the best way of preventing pathogenic outbreaks is to optimize the growing environment by reducing stocking densities, careful feed management, and maintaining an adequate exchange of good quality water.

One solution to this operating procedure of employing chemicals indiscriminately is for the regulatory agencies to intervene with education programs highlighting the harmful effects of these substances and ultimately fines to those operators unwilling to cease using such chemicals. The prevalence of antibiotics in the shrimp products ending up in the open markets of Thailand and the widespread use of chloramphenicol are particularly notable examples of the extent of the problem in Thailand. With increasing environmental awareness the issue of chemical usage in aquaculture will become a significant criterion influencing consumer acceptance and marketability of aquaculture products (Barg, 1992).

Improving feed management in shrimp farming operations

Improved feed management and diet quality, leading to reduced N and P in the feed and wastes and reduced FCR's will improve feed conversion efficiency and reduce waste and improve sustainability.

Effective ways to reduce pollution from shrimp farms is to regulate feed input (Boyd and Musig, 1992) and to improve the efficiency of uptake.¹³ With respect to the efficiency of feed uptake the most common way of calculating this efficiency in intensive aquaculture is to assess the Feed Conversion Ratio (FCR). FCR is defined as the ratio formed by the dry weight of feed consumed to the wet weight of shrimp gained. Generally FCR is expressed in relation to waste production (kg) per tonne of shrimp cultured and ranges between 1.0 to 2.5. To regulate the feed input involves reducing stocking density and/or more effective feed use.¹⁴

Reducing stocking density is necessary to enhance the contribution of natural productivity. Enforcement of this management technique is difficult to achieve in Thailand due to the large number of small-scale operations. Larger shrimp farm cooperatives or franchise ventures like CP farms can best take advantage of this management solution by controlling stocking density and through monitoring and restrictions on feed usage. These initiatives would provide example to the smaller operations which currently operate with established high initial stocking densities. Evidence from discussions with farmers are that they stock ponds high to offset potential losses. They are unaware of the benefits of keeping densities lower to improve pond performance. Local DOF officials need to demonstrate the economic benefits of adopting improved feed management systems.

¹³ A particularly uneconomical practice of the feed industry is the over fortification of shrimp feeds with vitamins to compensate for anticipated losses. Vitamins are the most expensive components of the feeds in some cases adding up to 10% of the total raw material cost (Csavas, 1994b).

¹⁴ Stocking densities ranging from 19 to 31 pieces/m² were reported to NACA (1994) by Samut Sakhon shrimp farmers.

Recommendations

- Rethink pond management practices to reduce pollution, reduce risk of disease and improve farm cycle performance through control of chemical use, reduction of stocking densities and improved control of feed inputs
- Educate farmers as to the potential damaging effects of continued over prescription of harmful chemicals (i.e. chloramphenicol). Chemicals are not effective and do not improve farm performance.

Improving farm system design and adopting treatment methods

The performance of shrimp farms can be improved by a systems approach using life cycle design which would incorporate resource recovery methods. Capital needs to be provided to small farms that currently are unable to retrofit their operations to introduce effluent treatment systems. Similarly, the performance of these small scale operations with limited land area and capital can be improved by education on life cycle design methods and assistance in resource recovery and pollution prevention approaches. Area-wide approaches should be adopted involving several farms so that the commonly used water supply is not a source of self pollution.

Use of life cycle design in the initial stages of establishing the shrimp farm necessitates a feasibility study being completed to determine the potential impacts of such limitations. The average small-scale shrimp farmer of Samut Sakhon does not have the resources. The responsibility in the future should be adopted by the local land use authorities and regulatory agencies. Ideally, in Samut Sakhon such agencies should meet with the potential shrimp farmers and suggest other low risk systems as alternatives to the intensive culture system.

Additional agency personnel, and an adequate land use plan are required to reduce the frequency and number of land use changes that can occur without planning. While the number of abandoned operations indicated the level of the challenge, individual responses observed during the field work show that some changes can be introduced with positive results.

Recommendations

- **Develop protocols to limit establishing excessive production capacities which exceed carrying capacity of the receiving environment.**
- **Increase presence of regulatory and other personnel in shrimp farming areas to introduce and discuss land use plans and low-risk aquaculture systems (i.e. lower intensity, incorporate life cycle design methods).**

Improving site selection

Site selection factors will become increasingly important considerations to improve farm sustainability. The decreasing availability of sites with less than "ideal" locational factors will force the adoption of adaptive designs in the engineering of new farms and in the modification of existing ones. This site selection process would identify that potential problems can usually be overcome prior to construction by major capital investment. The design and layout of a farm determines the ultimate productivity and environmental compatibility (Barg, 1992). Miyamura and Katoh (1986) have suggested six items for rational planning and designing of fisheries and aquaculture projects that could be appropriately applied to the Thai industry to improve the life span of the shrimp farm cycle. Adopting such an approach would demand that treatment systems become standard features of Thai shrimp farms.

Recommendation

- **Improve site selection factors, incorporate feasibility studies and promote inter-farm cooperation with water systems.**

Application of ecologically integrated technology

Analysis of the current practices of intensive shrimp culture operations in Thailand strongly suggest the need for both utilizing resources more effectively and adopting more ecologically sound practices. One of the properties of monoculture systems is that they rely largely on external inputs and only limited recycling of nutrients. What is perceived as ecologically sound farming, by utilizing resources more effectively, may not have to be associated with any great reduction of total output (Dalsgaard, 1995).

The intensive shrimp aquaculture systems in Thailand, as elsewhere, continue to pump the resources in, use them up and pump them out in a linear fashion, rather than being recycled. Analysis of the negative trends in farm operations highlighted the potential for modification to include on-site ecologically integrated technology. Biological production can be increased using bivalves in shrimp pond water management for the removal of algae and the removal of suspended solids (oysters, mechanical sedimentation). Also the inclusion of mangroves in treatment schemes and reforestation of degraded areas would assist in the introduction of ecologically integrated systems. These changes in operating practice involve moving away from standard practices towards the application of treatment methods for pond effluent and resource recovery techniques. The proposed solutions on these observations found many options available to Thai shrimp farmers and are presented below.

Recommendation

- **Improve shrimp farm system design to incorporate resource recovery techniques.**

Methods for waste effluent treatment in Thai shrimp farms

The application of treatment methods for the pond effluent brings the added benefit of resource recovery, added revenue for the shrimp farmer as well as considerable potential for reducing the impacts on water quality in the external environment. This is a common trend in aquaculture operations in temperate regions but was a much less observed procedure in the Thai industry. A major problem is the dilute but high-volume nature of aquaculture effluent in comparison to other forms of wastewater (Table 6.7). Despite this complication, cost-effective technology is now available to reduce loads of BOD, suspended solids, nitrogen and phosphorus. Table 6.17 summarizes a review of potential treatment methods of shrimp pond effluent in Asia (Phillips, 1992). These methods are suitable for application to the case study region.

Table 6.17 Treatment methods for shrimp pond effluent in Asia (Phillips, 1992)

Physical

- **Settling ponds:** Removal of particulate organic matter denser than water, but not efficient with phytoplankton

Biological - integrated marine aquaculture systems

- **Mussel and oyster:** Removal of particulate organic matter and phytoplankton from water column
- **Seaweed (*Gracilaria*):** Removal of dissolved nutrients (N and P) from the water column
- **Mangrove:** Removal of particulate organic matter and nutrients, but care required not to overload system. Careful assessment required.

Solutions using physical methods

Treatment of shrimp pond effluent can be split into physical, chemical and biological methods. Physical methods include filtration or settlement. It has been reported that a one-hectare settling pond is required to handle 900 m³ of shrimp pond effluent per day. Various treatment processes have been evaluated for the removal of suspended solids and soluble organic carbon. Filtration appears to be the best treatment process to reduce suspended solids, with less than 10 mg/L possible under various conditions. There is no doubt that physical treatment methods could be successful; however costs are likely to be prohibitive in Thailand. For a 10 ha pond in Hawaii, with effluent treated by screening and filtration (after which the water was reused), capital costs of \$US 137,500/ha and annual operating costs of \$US 75,000/ha were reported. Costs of this order are likely to limit the application of this technology in most Asian countries, and other cheaper options need to be explored (Asian Shrimp News, 2nd Quarter 1993). Once again major changes in funding policy by international agencies could make a substantial difference.

One alternative method is to use settlement ponds. However, shrimp pond effluent contains large amounts of phytoplankton and in these circumstances settling ponds advocated for removing solid wastes, are unlikely to be effective in treating pond effluent released during normal operation, because much of the solid matter discharged in effluent is phytoplankton, which are buoyant and remain in suspension for a long time (personal communication Funge-Smith 1993). These considerations have led to interest in biological treatment as an alternative.

Solutions using biological methods - integrated marine aquaculture systems

The effluent discharged during normal shrimp farm operation is rich in nutrients and microorganisms and is potentially suitable for the culturing of other species in an integrated marine aquaculture system. Thus, the scope exists to use methods of biological treatment to improve the sustainability of intensive shrimp farming operations.

Reports for Thailand on culture conditions, seed availability and marketability have identified potentially suitable species to be cultured in shrimp pond wastewater in Thailand as: cockles (*Anadara granosa*), oysters (*Crassostrea sp.*) green mussels (*Mytilus smaragdinus*), Nile tilapia (*Oreochromis niloticus*), mullet (*Mugil sp.*) and seaweed (*Gracilaria fisheri*).

In an integrated system the mollusk species, primarily filter feeders, would extract the suspended and detritus particles; mullets and tilapia are omnivorous species feeding on plankton, detritus and other bottom deposits; and seaweed can utilize soluble nutrients. Due to resource limitations in Thailand, such culture systems have been limited to the experimental species of Nile tilapia, green mussels and *Gracilaria*.

Each of the components of such an integrated systems will now be discussed for their potential to improving the sustainability of Thai shrimp farming operating.

Utilizing oysters and mussels to treat wastewater in integrated systems

Experiments using molluscs, oysters (*Crassostrea virginica*) in Hawaii and the green mussel (*Perna viridis*) in Thailand may be incorporated into integrated culture systems to treat the wastewater of shrimp ponds during normal operation.¹⁵ Oyster treatment was not sufficient by itself to meet discharge criteria. Oysters were reported to remove 12 to 15 mg of solid matter/g wet weight of oyster at suspended solid levels of 50 to 110 mg/L. Thus,. However, green mussels may be a more suitable species for application in Thailand.

¹⁵ The main genus being cultured in the tropics is *Perna* and main species of this mussel are *Perna perna* in India, Southeast Asia, Venezuela and South Africa, *P. viridis* in India, Southeast Asia and *P. canaliculus* in New Zealand. The green mussel (*Perna viridis*) cultured in Thailand is classified as follows: Phylum (Mollusca); Class (Bivalvia); Order (Fillibranchia); Family (Mytilidae); and Genus (*Perna sp.*).

Table 6.18 presents a general description of mussel culture applicable to Thailand. This culture method was observed in many of the canals in Samut Sakhon, including the Pitthayalongkorn Canal (Sample Station 1). It would therefore not be beyond the scope of shrimp farmers to incorporate them into the drainage systems of shrimp farms. In fact, several feasibility experiments of mussel applications have been completed which matched the appropriate shrimp culture method to the mussel assimilation capacities (i.e. the ability of the mussels to utilize the nutrients available in shrimp pond water) under different flow through systems (in mL/minute) (See Buakham, 1992). These experiments in Thailand show that the green mussels can reduce BOD, organic solids and phytoplankton.

Table 6.18 Stake culture in Southeast Asia (Quayle and Newkirk, 1989)

Description	Bamboo poles are driven into the bottom of the water with a depth of 2 to 10 m and spaced 1 to 2 m apart in rows. In some instances the single pole is supported by horizontal poles. Setting takes place on the poles and up to 200 spat/m ² , on an 8 cm diameter pole, are obtained.
Culture period	6 to 8 months is required to grow spat to approximately 50 mm in length.
Harvesting	By lifting the poles or by divers who are able to select market size mussels leaving the undersized mussels on the poles for further growth.
Production	14 kg/4 m pole or 50 MT of mussel annually from an area of 1 ha with 20,000 poles can be harvested in the Philippines.
Advantage	Simple method
Disadvantage	Depth of pole plantings and season are critical factors and require investigation.

There are several constraints to their application. Salinity fluctuation can cause mortality or reduce filtration rates while mussel faeces contribute to sedimentation. Mussels are also filter feeders and pose a risk to consumers by heavy metal accumulation in their tissues. This characteristic has been applied in the use of mussels in biomonitoring programs of coastal waters (Martin et al., 1988).¹⁶ This then suggests that any application in shrimp culture operations in Thailand, especially those in the Upper Gulf, would require monitoring of chemical contamination from shrimp farms and

¹⁶ Wang (1990) has suggested such criteria in the National Pollutant Discharge Elimination System (NPDES) issued by the state of Hawaii. Similarly, Chutchanchaipan (1994) has examined the contamination of coastal waters and mussel culture in the Upper Gulf of Thailand.

surrounding. The level of industrial activity in the Upper Gulf adds further complication to mussel culture.

Mussels may be suitably cultivated to treat shrimp pond effluent. However, they may only be useful as biomonitors in the Upper Gulf region due to the high concentration of industrial activity. Harvesting for consumption may not be possible. Already widely cultured in the canals of Samut Sakhon they can now be introduced to the shrimp farmers. Many shrimp farmers already possess the required experience in cultivating green mussels but they have yet to integrate them into shrimp farming operations.

Fish in the integrated system

The integration of Nile tilapia (*Oreochromis niloticus*), mullet (*Mugil sp*) and other fish species to control plankton and sediment accumulations may improve shrimp farm sustainability. These fish can be cultured in the same or separate ponds and would contribute to environmental quality, shrimp nutrition and farm income. This diversification of species cultured also reduces the farmer's reliance on a single species for income. Fish ponds in Thailand are a common method of food production. The information and experience available from these operations is extensive. The introduction of fish to the shrimp farm cycle can be viewed as a requirement for sustainability of the farm systems. Field observations from the various shrimp farming regions of Thailand indicate that fish are commonly used only by the larger operations and then only in water reservoirs and they have not been used by the small scale intensive farmer.

Seaweed in the integrated system

The seaweed *Gracilaria* is an attractive species to grow in polyculture with mussels in a biological treatment system, because it can remove soluble nutrients (nitrogen and phosphorus) which are not absorbed by molluscs.¹⁷ Several experiments have been carried out in shrimp pond effluent water in Thailand, although such systems have yet to be taken up on a widespread commercial scale. Disadvantages include sensitivity of some species or strains to salinity fluctuations, light limitation in turbid waters and smothering of weeds by solid matter and microbial growth in the highly turbid shrimp

¹⁷ Polyculture is the rearing together of more than one species (sometimes as many as six or seven) in a pond.

pond effluent. One advantage of *Gracilaria* is that it can be processed for extraction of agar as an additional source of income (personal communication Funge-Smith 1993). *Gracilaria* has potential to be cultivated in the Upper Gulf of Thailand to remediate abandoned ponds. The simple methods of seaweed culture make this attractive to small-scale operations in this region.¹⁸ This method is reminiscent of the purification of waters using wetlands treatment used in North America.

Biological treatment systems combining the culture of several organisms offer scope to improve effluent quality. These treatments of shrimp farm effluent provide an environmentally attractive line of research and development which should be widely supported in the long term interests of improving sustainability. These ecosystem-based approaches, if widely adopted, will assist in alleviating many of the current problems with shrimp farm effluents.

Improving performance of biological methods by modifying harvesting practices

The quality of effluent discharged during harvesting and pond cleaning is so poor that biological methods, such as those mentioned above, will not be sufficient. One strategy is to harvest at the pond outfall, without disturbing pond sediments. Ideally, harvesting should be followed by minimal sediment disturbance, followed by drying, oxidation and liming to enhance oxidation of organic matter. If practices demand that sediments must be disturbed, the use of settlement ponds to remove this potentially very damaging effluent may assist.¹⁹

Biological treatment using mangrove-aquaculture systems

Mangroves have been identified as part of an ecologically-viable aquaculture technology to treat shrimp pond effluent, either by retention of a mangrove buffer zone close to the shrimp ponds, or by replanting mangroves for deliberate purpose of water treatment. Mangroves have been successfully used as a tertiary treatment for sewage effluent in the USA, although care is needed to avoid overloading the treatment system with nutrient

¹⁸ For example, it was explained that all that is required to stimulate growth of seaweed in these ponds is for the farmer to wade through the pond daily to stir up settled materials and stimulate biological activity.

¹⁹ The practice of discharging such effluent into common water bodies in Thailand although illegal is widely observed. Shrimp farming operations have insufficient land to use settlement ponds prior to discharge and do not fear punishment from such illegal activities.

and organic matter. Thus, there may be potential for combining mangrove with semi-intensive shrimp culture in what could be a sustainable and environmentally sound integration. Further study is needed to fully understand mangrove systems and how to apply them as shrimp farm treatment systems (personal communication, Phillips, 1993).

Efforts to implement this alternative must start with conservation, reforestation and implementation of existing pro-conservation laws. Future aquaculture operations may be integrated with mangrove forests in which the operations are complimentary with intact mangrove areas functioning as treatment filters for the effluent produced in aquaculture operations. It is important however to note that the correct size of forest required for an aquaculture operation is difficult to accurately match to the size of mangrove forest required. Robertson and Phillips (1994) examined the use of mangroves as filters of shrimp pond effluent. Studies have looked at the effects of wastewater discharge on nutrient contamination of mangrove soils and plants and are a beginning to much needed research efforts. Preliminary results in a study by Wong et al. (1993) indicated that a gradual discharge of a total volume of 2,600 square meters of municipal wastewater to an area of 1,800 square meters of mangrove plants over a 1 year period seemed to provide no apparent impact on the plant growth, soil and nutrient content of the ecosystem. It is commendable to undertake research on the use of mangroves for treatment and filtering of the effluent from shrimp farms.

Recommendation

- **Promote the application of ecologically integrated systems and methods (physical, biological)**

Development and application of the closed culture system

Upper Gulf coastal aquaculture stations are experimenting with 'closed' shrimp culture systems (Wanuchsoontorn et al., 1993). This method, first developed in this region, has been prompted by the repeated failure of farm cycles using conventional methods. The likelihood of continued poor water quality due to pollutants has also provided incentive.

The Upper Gulf closed culture method has been reported by FAO/NACA (1995). A water storage pond of equal capacity to the shrimp farm grow-out ponds must first be

constructed. Water is pumped into the storage pond and kept for a 1 month period. The water is then treated with a 10 ppm solution of chlorine over a 1 week period. When verified that the water is free from chlorine, the water is used to fill the grow-out ponds in 10 % increments. From this point onwards the water in grow-out ponds will not be drained for the duration of the grow-out period. The stocking rate is generally 20 PL/m² and the water depth is maintained at 1.25 m. Over a 4 to 5 months, a 0.16 ha pond will yield 600 kg or 3,750 MT/ ha. Browdy (1995) provides comparative examples of similar production methods with no discharge situations that have achieved yields of up to 7,000 kg/ha/crop. Application to the Upper Gulf farms and in other regions shows promise. The DOF has recognized this and is currently developing a strategy to promote this method. When the crop is harvested the ponds are drained so what is understood as a closed cycle (continuous use of water) is not yet in place.

Such systems represent a change from open flow through systems and are particularly relevant to the Upper Gulf region. The benefits from the application are in the possibility of reintroducing 'idle' land into production and it allows some level of shrimp culture in an area where traditional flow-through systems no longer possible. Trial results from the Phetchaburi stations have been reported by Anand et al., (1994). Pond yields with PL stocking densities of 18.75 (187,500 PL/ha), 62.5 (625,000 PL/ha) and 93.75 (937,500 PL/ha) pieces per meter squared were 2,188 to 3,438, 8,125 to 9,375 and 12,250 kg/ha respectively.

Despite some positive results the widespread adoption of closed culture systems is unlikely for several reasons: (1) most shrimp farmers cannot afford the high cost of land conversion and (2) use of such a system would require a method to store or stock water in reserve, primarily by reservoir, with enough capacity for the duration of the grow-out period. Farmers are unwilling to sacrifice farm area, previously dedicated to production, to construct the reservoir. The reservoir in a closed system becomes the only water source available to the shrimp farm. No external water is drawn from available sources after initial stocking and treatment. Few farms have adopted the 'closed cycle' and the shrimp farmers in the Upper Gulf have a wide interpretation of what is considered a 'closed' system.

Recommendation

- **Continue trials of “closed culture systems” and further refine end use disposal methods for harvest effluent from closed systems.**

Restoration, remediation, and mitigation to restore damaged ecosystems

No remediation, reclamation or restoration of abandoned or derelict intensive shrimp farming regions, including the areas in the province of Samut Sakhon, will be successful without the full endorsement and support of the government agencies.²⁰ This will include, at a minimum, the re-organization and enforcement of policies developed to protect the coastal zone. Unless the shrimp farmers are persuaded to comply to codes of practice there will be little progress towards sustainable shrimp farming.

A number of strategies have been suggested for abandoned shrimp farming regions in Thailand (e.g. See OEPP, 1994a,b). However, the effectiveness of such measures has yet to be demonstrated. Some of the possibilities for abandoned shrimp farm areas includes replanting mangroves (afforestation), pine trees (*Pinus casuarina sp.*) tolerant of saline soils or the camachile tree (*Pithecolobium sp.*), and cashew nut plantations. These are just some of the trees which can grow well in the coastal areas of Samut Sakhon that have been identified as suitable for replanting in the saline soils of derelict farms outside of designated coastal mangrove areas (OEPP, 1994b).

Recommendation

- **Implement and enforce pro-conservation laws, consider reforestation in abandoned areas**

Mangrove afforestation

Mangrove replanting programs have been initiated by many national governments who realize that large-scale mangrove conversion into fish and shrimp ponds has displaced rural coastal communities which traditionally depended on mangrove resources for their livelihood (Chua, 1993). Ironically, some countries that obtained loans from

²⁰ All three of these efforts represent a different degree of ‘repair’ for the damaged ecosystems of derelict shrimp farms.

multinational banking institutions to convert their mangrove wetlands into shrimp farms are now borrowing again from the same banking institutions to replant the mangroves! These efforts are hampered by several aspects of the conditions that remain after shrimp farming has failed. The low level of soil fertility and high acidity in abandoned shrimp farming areas represent changed environmental conditions in the former mangrove areas. Before replanting mangroves the soil must first be improved by increasing the organic matter and establishing plants that can tolerate the highly acidic soils. In the beginning, fast growing plants with shorter life-cycles, such as, grasses or legumes might be planted. The organic matter from these plants would improve soil structure and fertilize the soil. The previous shrimp pond dikes which obstructed the tides should be demolished or leveled. Free communication with tidal waters, a source of nutrients, will facilitate the gradual improvement of the mangrove ecological system back to its natural condition. As with any effort there are associated costs

In summary, the restoration of disturbed or degraded ecosystems, such as those typically found in shrimp farming areas, will gain support only if society accepts and understands the importance of ecosystem services. To demonstrate this importance indicators are being developed to monitor regional ecosystem health. Agencies undertaking this work recognize the importance of maintaining ecosystem viability and that natural life support systems can provide services less expensively and more reliably than technological systems. Examples demonstrating that these concepts are reaching the consciousness of the general public are being aided by a growing literature on the subject of repairing damaged ecosystems.²¹ Environmental rehabilitation and management depend upon the availability of organized data and information on the state of the environment, its trends and their relationship to socioeconomic factors.

Recommendation

- **Research the prospect of using mangrove-aquaculture systems to treat effluent by replanting or using buffer zones close to shrimp ponds.**

²¹ For an excellent example, see the recent work edited by Cairns (1995) entitled: Rehabilitating damaged ecosystems.

6.7.3 Institutional structures

BARRIERS

In Thailand, many institutional challenges to sustainability exist. Investigation of Thai government departments affecting the activity of shrimp farming revealed that they are numerous and segregated along sectoral lines (Table 6.19). Policies related to resources and environment have not been well coordinated or linked among the numerous agencies. The end result of such fragmentation is that institutional structures in Thailand have not yet been able to develop and implement effective controls in response to shrimp farm development. This reality, in common with most countries (states and provinces), makes it difficult to address sustainability issues that involve linking economic, environmental and socioeconomic considerations.

Table 6.19 Thai Government departments responsible for coastal resources which affect shrimp farming areas (Modified from Paw et al., 1988)

Ecosystem	Mangrove				Beach				Estuary				Mud flat			
	A*	B*	C*	D*	A	B	C	D	A	B	C	D	A	B	C	D
ONEB	X	X			X	X			X	X						
LDD		X				X				X						
RFD	X	X	X							X	X			X	X	
DOF										X	X			X	X	
DAE										X	X					
DMR			X			X					X					
HD						X					X					
TCP						X	X									
TAT						X										
NESDB	X				X					X						
NRC				X									X			X

*A-Policy; B-Planning and Management; C-Implementation; D-Research

Key to abbreviations:

ONEB: Office of the National Environment Board

LDD: Land Development Department

RFD: Royal Forestry Department

DOF: Department of Fisheries

DAE: Department of Agricultural Extension

DMR: Department of Natural Resources

HD: Harbor Department

TCP: Town and Country Planning

TAT: Tourism Authority of Thailand

NESDB: National Economic and Social Development Board

NRC: National Research Council

No single national agency is responsible for coastal management or has jurisdiction over both marine areas and coastal lands. In relation to aquaculture, the DOF is in charge of developing policy, planning and implementation of aquaculture initiatives (Table 2.24) and mangrove areas fall under the control of the RFD. Attempts at inter-sectoral cooperation have been ineffective to date. This lack of cross-sectoral coordination has contributed to continued mangrove depletion, coastal water degradation and resource use conflicts.

Institutional arrangements and support for coastal zone planning, implementation and management have divided the ecosystem into compartments: air, land, water and biota and even smaller units. Such compartmentalization fails to recognize the interconnections within coastal ecosystems. For example separate responsibilities exist for mangrove, beach, estuary and mud flats. Aquaculture and other uses of the estuarine, coastal and marine ecosystems have also not been treated as integrated, but rather as isolated sectors resulting in the failure to account for the environmental costs of aquaculture. Accordingly, policies and legislation have been fragmented in approach and achieved limited success.

Rapid development of aquaculture has outpaced coordinated response

Substantial loans for aquaculture development projects have not been matched with improvement of institutional capacity to control such rapid development (i.e. unable to control, enforce and properly monitor). The institutional agencies capacity has not grown rapidly enough to keep pace with perhaps, too adequately funded, development.

Capacity of newly formed environmental protection agencies

New environmental protection agencies, created under NEQA in 1992, are now attempting to increase their role in the regulation of shrimp farming. However, they are meeting with resistance from well established government ministries (e.g. the Interior Ministry). For example, fledgling environmental protection departments like the newly formed Pollution Control Department (PCD) are tasked with ensuring ongoing attention to environment related issues. The PCD is ill-equipped to meet this task in the current institutional structure nor has the PCD achieved integration with resource, and finance/economic departments. The PCD has several ongoing projects related to aquaculture development which are discussed below.

Limited enforcement and effectiveness of policies

Positions, policies and plans with respect to achieving sustainable coastal shrimp aquaculture have been difficult to implement in the current institutional structure. Direct evidence in Thailand includes: increasing loss of mangrove habitat despite regulation; failure in registration of shrimp farms and hatcheries although officially required by the DOF, lack of treatment systems that comply with legislated requirements; use and over prescription of non-registered chemicals despite indications of the potential for human health problems. All of these practices occur with very limited enforcement by existing agencies with mandates to control such practices.

SOLUTIONS

All of the national agencies have the capability to increase their effectiveness. Strengthening of environmental regulations, fostering of global environmental governance and reforming of economically based institutions are several key areas on which to focus. Improving institutional capacity (i.e. capacity building) should be incorporated as eligibility requirements for all aquaculture development loans. The characteristically rapid growth of aquaculture demands that both institutional and societal capacity to address environmental problems also be increased. Societal capacity refers to public awareness and education. Human resource capacity refers to trained personnel. There are a growing number of examples within Thailand which suggest that reform of institutional structure may be hastened through the efforts of non-government agencies and consumer groups. In fact, these groups have been more efficient in identifying the problems than the current institutional system. They have been most affected by the events leading to the destruction of coastal areas in which they live. It is suggested that strengthening of the agencies, interagency cooperation and involvement of the public in Thailand will be important factors in the solution.

Recommendations

- **Increase inter-sectoral cooperation between the DOF and the Royal Forestry Department on mangrove afforestation in abandoned areas**

- **Recognize the interconnectedness of ecosystems. Incorporate ecosystem based management concepts in agencies with the power to intervene in the different parts of the ecosystem (i.e. decrease segregation of the coastal zone)**
- **Incorporate the requirement for capacity building in loans to aquaculture development**

Role of NGO's

The role of non-government agencies (NGO's), community groups and consumers in achieving sustainability is changing. In Thailand, the well known NGO Yad Fon Association, has worked with great success in at least 17 coastal communities. Community managed mangrove forests have been established in many small villages offering a very positive model for surrounding communities to follow. Reforestation and conservation efforts have proven themselves in increased fish yields and enhanced livelihoods for participating communities (Quarto, 1995). A growing number of organizations are striving to implement changes in the current industry. The following quote by Khor (1995) which appeared in a magazine entitled *Third World Resurgence* illustrates some of the sentiments of the communities affected by shrimp farming operations:

“An increasing ground swell of social discontent is developing in the Asian region against the adverse effects of shrimp aquaculture. Community organizations and ecology groups are intensifying their protests against shrimp farms in various countries, including India, Bangladesh, Thailand, Malaysia and the Philippines.”

Largely missing from the current debate over intensive shrimp farming are the views from inhabitants who have firsthand knowledge of the effects of intensive shrimp farming. Their accounts are worth consideration as they have borne the brunt of past mistakes. Opinions regarding shrimp farming from local inhabitants are varied and numerous, and local community concerns often contradict the views held by government planners. Public involvement in institutional planning related to coastal resources may improve the effectiveness of institutional measures by gaining public cooperation. Institutional planners would benefit by remembering that coastal zone management is not only concerned with managing the natural resource, but also people (Tisdell, 1989).

Recommendation

- **Increase the involvement of NGO's in decisions. Recognize that they have direct experience in dealing with the environmental impacts**

Consumers as advocates for sustainability

Consumers may become advocates for sustainability in the industry. Organized boycotts are one example of how consumers may improve the sustainability of shrimp farming though negative economic consequences for Thai farmers in the short term may result. The behavior and preferences of the consumer with respect to shrimp products ultimately affects the performance of the industry since consumer perception of the quality of the product will determine long-term success. Environmental ethical methods of production may become a "quality" factor in the consumer market.

For the moment the worldwide consumption of seafood has risen concurrently with a desire to improve quality and safety. The U.S. Centers for Disease Control (CDC) have recorded only 11 outbreaks of seafood disease attributable to shrimp consumption between 1978 and 1987. The principal hazard from contaminated raw shrimp is the possibility of cross-contamination with cooked products. These incidents have prompted importing countries to formulate some protective measures. For example, the European Union (EU) has produced the EC Shellfish Hygiene Directive (91/492/EEC) which sets out requirements for live shellfish exported to the EU.

Recommendations

- **Industry must accept that the preferences of consumers may influence future product desirability. Incorporate the changes to their operations prior to this event.**
- **Improve import and export testing of all shrimp products. Accurate information regarding quality and safety is lacking.**

Strengthening environmental protection agencies

Some government agencies in Thailand are undertaking initiatives that include the mitigation of pollution in the coastal area and to control the effluent from aquaculture,

through establishment of standards and appropriate management practices. These actions are being implemented in accordance with the *Environment and Conservation of the National Environmental Quality Act. B.E. 2535*

Early in 1995 the PCD commissioned a detailed assessment on the legal framework and other policies concerning coastal water quality, effluent standards and management of pollution from coastal aquaculture. The report should provide valuable information to assist in establishing effluent and water quality criteria for different areas along the coast of Thailand.

Examples of other positive approaches towards environmental management in Thailand have been identified. Primavera (1992) has suggested tax incentives for farmers operating waste management systems. Tax incentives are now being discussed in Thailand at a very preliminary level and may include aquaculture in a group of coastal resource industries that rely on water resources.

Recommendation

- **Strengthen the powers of the environmental protection agencies within the current power structure (increased capacity to act)**

6.7.4 Policies and legislation

BARRIER

In Southeast Asia, as elsewhere in the world, environmental laws are under serious strain. Rapidly changing conditions being created by industrialization, urbanization, agricultural development, and an expanding population have led to pressures to relax environmental regulations. Laws are characteristically fragmented and lacking the uniformity and internal consistency necessary for ecologically responsible development. All Southeast Asian nations lack environmental laws that can accommodate the divergent pressures for modernization, nationalism, and the preservation of tradition (Reynolds, 1981). Similarly, many countries have no lead agency for aquaculture and lack a coherent national policy which promotes rather than discourages inter-agency cooperation (Rosenthal, 1994). A major criticism directed towards aquaculture is that

development occurred without long term (or even short term) strategy. As a result, in the shrimp farming industry, conflicts and severe environmental problems have emerged.

The rapid development of shrimp farming in many Asian and Latin American countries has been faster than the legislative process. Most of the laws drawn up originally for the conservation of wild fisheries, or agricultural practices have been applied to aquaculture with varying degrees of success (Howarth, 1994).

The Thai situation

The profusion of laws, regulations and decrees confuses the situation in Thailand and enables well-financed groups to find loopholes. Between 1978 and 1987 no less than six decrees were issued by the council of ministers showing concern for the degradation of the coastal mangrove reserves, most of which overlapped each other. It took until 1987 to classify and regulate the use of mangrove areas comprehensively.

Central government policies directing the DOF

The government of Thailand, like many other countries, operates according to pre-established policies contained in National Economic and Social Development Plans. One of the mandates of the current Seventh National Plan calls for the improvement of the quality of life in the rural areas. The government wishes "to develop a foundation for sustainable development and a national heritage for the younger generation". These statements and policies put forth by the government establish the climate in which the activity of coastal aquaculture can develop. Concerns with regards to the performance of these policies are valid. Many argue that resource exploitation has been the primary activity and that adequate conservation measures for coastal ecosystems have not yet been emphasized with equal importance. Part of the problem is that the language of the policies allows for a wide interpretation by different groups with opposing interests. In the absence of any clear directives opportunistic shrimp farmers have been able to operate without concern or respect for ecological limitations.

Evaluation of the DOF's Twelve Point Plan

The individual aspects of the DOF's twelve point plan presented in Table 2.21 are discussed here in terms of progress towards sustainability.

1. **Deepening the shallow ditches and canals.** Budget increases have been allocated to improve water supply and drainage systems in several provinces (Samut Sakhon, Samut Songkhram, Surat Thani, Chanthaburi and Nakhon Si Thammarat). Shallow canals that have large sediment accumulations will be deepened to improve water flow. The budget to complete this task was increased from \$US 963,000 in 1990, to 3.1 million in 1991 and 12.4 million in 1992. The objective is to improve the performance of shrimp farm water supply and drainage systems. The status of these projects is ongoing. Few results will be achieved in these shrimp farming regions if the practices of the individual farm units are not improved to reduce the substantial sediment outputs to the canal systems. In Thailand, the large number of small-scale operations makes this a difficult task.
2. **Reduction of production cost.** Most provincial coastal aquaculture development centers have undertaken projects on model farm practices that would minimize environmental impact and optimize resource utilization. The idea is to then transfer these skills to the farmers as suggested in the National Plan. Research in Samut Sakhon is directed at the needs of the farmer and is divided into seed production techniques, culture techniques and environmental factors.
3. **Saltwater irrigation systems.** The goal of these projects are to improve water availability to 16,000 hectares of land area by separating source water from waste water. The results should support farmers in achieving higher yields in the physically constrained farming areas by improving the saltwater flow systems. The targeted regions, all located in Southern Thailand, are Chanthaburi, Ranot and Songkhla. In 1994, the DOF awarded a \$US 8.8 million construction contract with several Thai agencies to construct saltwater irrigation systems for shrimp farms in Ranot and Songkhla (Anon., 1994c). The problems reported in implementing the project are in difficulties in the appropriation of required land.
4. **Improved culture techniques.** In 1989, the DOF commissioned a 320 hectare demonstration farm in Southern Thailand. Published information from this now terminated project was not available to report here. An earlier pilot demonstration farm located in the Upper Gulf region, the first of such projects, has also been closed for some time.
5. **Designated shrimp culture zones.** Consolidation of some of the complicated laws would allow areas to be designated as shrimp culture zones where shrimp farmers could be assisted with technical expertise, water delivery and removal systems. Farmers applying for permits to operate in areas not within designated culture zones would not be granted registration by the DOF. A complicating factor with respect to aquaculture management is the lack of comprehensive land use plans specifically developed for each province. The DOF personnel have unofficially stated that the policy with respect to Samut Sakhon is to return 30 % of abandoned farms back to intensive operations, 30 % being estimated as a suitable percentage of intensive operations for the area.
6. **Quality control of shrimp larvae.** In 1989, a ministerial decree stated that all shrimp hatcheries must register. As of 1994, only 10 % of the hatcheries had yet to register. The intention of this plan is to test for the quality of the PL shrimp and to certify hatcheries whose PL shrimp perform well. The low compliance to this decree currently hinders the efforts of the DOF to control shrimp larvae quality.

7. **Registration of shrimp farmers.** A Royal decree issued in 1991 to facilitate DOF planning which would facilitate the compilation of data on shrimp farming, the systems used and yields obtained. The benefits of registration was access to the skills of DOF staff, including diagnostic work and the provision of compensation in the event of natural disaster, flooding etc.
8. **Control of feed quality.** The Feed Quality Act (1982) stipulated that all shrimp feed manufacturers must adhere to set quality standards. The manufacturers must declare nutritional information about their feeds and avoid the use of moist and semi-moist feeds. Improvements in feed quality have the potential to reduce the environmental impacts associated with their use. A target Feed Conversion Ratio (FCR) of 1.5 would be set in the utilization of dry pellet feeds, which although are more expensive per kilogram, have higher food-to-weight ratios and thus the advantage of improved FCR's. Dry pellet feeds thus have the advantage of lower wastage and less chance of carrying disease.
9. **Control of chemicals and hazardous substances.** To be enacted through the Feed Quality Act transferring the responsibility of enforcing aquaculture drug use restrictions from the Ministry of Health Drug Administration to the DOF.
10. **Cooperation with the private sector.** Drug residue testing made available to private shrimp farmers and prevent them from being taken advantage of by buyers and processors.
11. **Determine the environmental impact of shrimp culture.** Implement a field sampling program that monitors the whole culture environment from pond PL stocking through the grow-out period. Soil, water and other environmental parameters will be monitored by the DOF.
12. **Establishing effluent water quality standards for shrimp farms.** Effluent must have a BOD level less than 10 mg/L. Shrimp farms over 8 ha must have settlement ponds equal to 10 % of the total pond area. The BOD standard is not a truly effective water quality standard for shrimp farms. Farmers can easily avoid exceeding the effluent level by dilution of the effluent concentration with available water supplies.

To date, the DOF has been unable to effectively fulfill all of the above coastal aquaculture objectives through established policies. Efforts have been hampered by poor compliance with effluent standards, slow registration of farms, combined with use of banned chemicals and lack of mitigation activities. Political will to enforce legislation is needed to achieve sustainable operations.

SOLUTIONS

The relevant legislation in Thailand is of two kinds. Legislation concerned with water quality and more general legislation that functions to regulate aquaculture activity. The regulations seem straight forward enough, and have the potential to lessen the

environmental impacts of shrimp farming, and therefore to reduce the problems faced by the industry.

One positive approach being pursued is the adoption of various legal measures that would specify permissible levels of pollution of the different sources. This was seen in the enactment of the *National Environmental Quality Act (NEQA) 1992* and the subsequent enforcement of various regulations under the provision of the act. In the enforcement of regulations, the underlying principle is to set effluent standards that take into consideration the practical situation. For instance, the effluent standards for aquaculture should be progressively tightened over time to allow time for compliance whilst ensuring that enforcement is not 'economically' disruptive. Initiatives using the above thinking have been initiated in Thailand. The PCD is attempting to designate appropriate standards for the effluent of coastal aquaculture and to develop measures and a management plan for control of coastal pollution resulting from aquaculture effluents. The author was involved with the initial stages of this project through connection with NACA and a draft version of the report was submitted to the PCD in April 1995. A fundamental problem exists in this approach. Too much emphasis is placed on not being 'economically' disruptive. Further, there is a weakness inherent in the establishment of environmental effluent standards as a means of environmental protection. While it is possible for aquaculture operations to comply with the standards, the total levels in the environment would still be unacceptable when all the discharges are added together. A regional pollution prevention approach would be preferable.

Another approach would be through environmental planning to prevent or minimize environmental problems at the project planning stage. At the project level, this can be illustrated by the requirement for an environmental impact assessment (EIA), which came into effect on 24 August 1992 in Thailand. Since 1981 EIA had previously only been applied as a tool for environmental planning and management. However, the NEQA 1992 gives the Minister of Science, Technology and Environment, with the approval of the National Environment Board (ONEB), the power to issue notification prescribing the projects or activities which are required to submit and EIA report to the Office of Environmental Policy and Planning and the Review Committee for consideration and approval before further proceedings.

At present, there are no EIA requirements for the siting of aquaculture projects and introducing them would be a positive step. Some proponents have taken the initiative and prepared comprehensive EIA's for aquaculture projects in order to demonstrate their commitment to the environment. It is expected that given the serious problems identified with respect to the impacts of aquaculture that these projects will eventually require EIA's under the NEQA. However, the legal requirement for EIA under NEQA will not solve all the problems. Since EIA deals with environmental issues at the project level, it is possible that environmental conflicts will still occur even if EIA's were conducted for individual projects, when incompatible forms of coastal zone uses have already been established such as the siting of industries next to aquaculture areas. Such situations, can, and should be, avoided at the regional plan level and combined with an EIA approach.

Recommendation

- **Increase accountability of operators for environmental damages (reverse onus on potential developers)**

Scale of operation

The 'scale' of operations in Thailand suggest different that approaches need to be taken for small scale and large scale operations. Assistance from regulatory agencies must focus on solutions that assist the small scale operations which now comprise almost 80 % of the number of farms in Thailand. In order for the recent environmental regulation to be effective regulatory agencies must suggest approaches that would allow these small holding to meet the cost of water treatment and storage. Cooperatives have been established for some small scale holdings in Southern Thailand with some success. These solutions have to be carefully introduced.

With respect to larger shrimp farming operations the regulatory agencies can take a more forceful approach. These operations are generally better equipped to meet the costs for achieving compliance. Such costs generally represents a marginal cost for large company operations which can benefit from the economies of scale and increased access the capital. It should be noted that such "solutions" do not take into account cultural or community factors of employment and ownership. These are then the attributes which

must be carefully considered by the regulatory agencies in dealing with smaller scale operations.

Recommendation

- **Determine practical methods of enforcing the standards. Make them achievable to small scale operators and punish larger scale operations for breaking the law**

6.7.5 Planning and information systems

BARRIER

The current planning, information and environmental management systems in Thailand designed for environmental problems of the shrimp farming industry, have not achieved effective levels of development. Inadequate research on biophysical (land and water) resource utilization has allowed for inefficient channeling of resources for aquaculture development and hampered formulation of appropriate strategies and subsequent management. Lack of reliable information for policy makers has lessened the effects of national policy formulation.

SOLUTIONS

The introduction of appropriate management tools is essential. These include: environmental impact assessment specifically for aquaculture, application of ecological risk assessment techniques and the adoption of environmental management systems (EMS). All of these are techniques and approaches which when combined with a national plan can lead to faster action in meeting the sustainability requirements for the current aquaculture industry which currently operates without many of these tools.

Application of environmental risk assessment (ERA)

The application of environmental risk assessment techniques to aquaculture ventures is fundamental if sustainability is to be achieved. The risk of failure of intensive aquaculture operations is considerable and it has been stated that the growth of the industry has been seriously hampered by the lack of understanding of the part of both

financial institutions and insurers (Kingsley, 1986). Wile (1993) advocated the practical application of environmental risk assessment techniques to aquaculture operations. The intent was for the assessment of risk in establishing and insuring aquaculture ventures. The approach bases the risk assessment on the following factors: competence, biophysical environment, farm-design and technical factors. The use of risk assessment in aquaculture should figure prominently in the future of aquaculture as investors and insurance agents are no longer willing to accept aquaculture as a profitable risk free endeavor. Evidence suggests otherwise and investors and loan agencies may indirectly improve the performance of shrimp farming operations by forcing them to examine the risks prior to start up. To be truly effective, the application of these techniques must expand the view towards the ecosystem beyond the farm to a regional level.

Recommendation

- **Apply ecological risk assessment techniques in all shrimp farm developments**

Environmental Management Systems (EMS)

The current Thai shrimp industry is at a critical juncture in its development. The widespread adoption of an EMS can potentially improve the long term sustainability of the industry. The recent standardization of EMS being introduced by the International Standards Organization (ISO) 14000 Series now offers the opportunity for the industry to adopt such a system. This series was developed to provide guidance and assistance to organizations that are implementing or improving an EMS, regardless of size, type, or level of sophistication. Such initiatives stem primarily from the June 1992 United Nations Conference on Environment and Development (UNCED). This series provides the opportunity for shrimp farming industries to support the UNCED goal of sustainable development. For shrimp farming they offer a systematic approach with many potential benefits addressing a number of aspects of the current Thai shrimp industry. Such a system would address consumer's increasing environmental expectations; satisfy investor and vendor certification criteria (also expected to become more stringent); demonstrate due diligence; and practice the conservation of inputs of materials and energy to name just a few. These aspects indicate that there will be difficulties to overcome in adopting these factors and suggest that solutions must be aimed demonstrating the benefits so as to achieve widespread adoption by the shrimp

farming industry. In order for such systems to be effective they must be accepted by all. EMS is currently intended for use as a voluntary internal management tool.

Recommendation

- **Incorporate environmental management systems in accordance with ISO 14000**

Application of remotely global positioning systems (GPS)

The rapidly developing technologies based on Global Positioning Satellite System (NAVSTAR) have many applications for the shrimp farmer. As greater emphasis is placed upon the environmental factors affecting the industry (i.e. limitations to sustainability), it is essential for the farmer, whether building a new farm or re-conditioning an existing farm, to possess the ability to cost-effectively gather accurate and accessible environmental data that can be incorporated into a geographic information system for study and analysis. This information can be readily obtained using GPS technology. The construction (or re-construction) of a farm can be much faster and cheaper using GPS technology for topographical surveys, construction stakeout, and monitoring construction in progress. The future applications of this technology for the Thai situation are inhibited by cost and introducing and applying such informational tools at the farm level. There is a readily identified role in the application of such systems by regulatory agencies for environmental protection measures (i.e. determination of 'illegal' shrimp farm operations in protected mangrove areas by the DOF and the RFD).

Recommendation

- **Utilize GPS in environmental protection applications (i.e. marking out the mangrove conservation areas and determining where illegal farms are located)**

Application of remotely sensed geographical information systems (GIS)

Integrated planning is frequently cited as a priority for aquaculture development and there are several examples where GIS has been successfully utilized in determining aquaculture site location (e.g. Costa Rica; Scotland). A FAO-UNEP/GRID cooperative study in Costa Rica (1987) in the Gulf of Nicoya identified optimum locations and land

and water surface areas available. However, under the ASEAN/US Coastal Zone Management Program (CZMP) Kam et al. (1992) identified constraints to the use of GIS.

Progress has been made applying satellite-based remote sensing technology to the management of natural resources. The aim is to improve resource allocation. Satellites can cover large areas repetitively and collect vast amounts of data, making possible regular monitoring. Extensive application is hindered by cost, lack of familiarity with the methodologies, lack of technical expertise and inaccessibility of remotely sensed data.

Remotely sensed data is utilized in the locating and establishing of shrimp farms, including analysis of estuarine areas that are experiencing the inputs of effluent from operating shrimp farms is an area that requires research. In the use of satellite, SPOT, imagery to examine effluent from a region, the DOF were attempting to correlate the imagery with measurements of water quality parameters, particularly, the concentration of NH₃ (e.g. the Kung Krabaen Project Station/Asian Institute of Technology study).

A project that focused on the growth of Ecuador's shrimp mariculture industry utilized remote sensing to identify or detect shrimp ponds. Once these figures were tabulated the research group subtracted the 'authorized' shrimp ponds to establish those which were 'illegal'.

A project in Thailand monitored land use/cover changes in the province of Chanthaburi. The use of remotely sensed information in the designation and protection of mangrove resources by Tookwinas and Leeruksakiat (1994) found that a 16 % increase in shrimp farm area was closely matched by a 27 % reduction in mangrove area. The information established that mangrove deforestation can be attributed to human activities. Such information is essential to increase the effectiveness of planning and information systems. This information concerning the expansion of shrimp farming can now be used to assist in future determination of suitable areas for shrimp culture and assist in the development of reforestation plans.

Water management for aquaculture is another application of remote sensing applications. Some of the tasks for remote sensing in this application are found in Table 6.20.

Table 6.20. Water management tasks for remote sensing applicable to shrimp farm development (Modified from Mainkiam, 1995).

1. Surface water management: Information on rivers and lakes by estimating surface area and volume.
2. Irrigation potential: Assessment of irrigation requirements.
3. Water quality assessment: Satellite data are highly sensitive to changes in sedimentation and particulate matter suspended in surface waters.
4. Environmental impact of river valley projects: Quantifying land use changes.
5. Mitigation of water-induced disasters.
6. Integrated resource management for sustainable development.

The use of GIS will become increasingly important as investors seek to minimize the risks involved in aquaculture development. A current field of interest in the application of GIS is in the investigation of marine pollution (Clark 1993). This supports the importance of the use of GIS in locating aquaculture activity in heavily industrialized areas such as the Upper Gulf of Thailand.

Troost et al. (1994) reported on marine and coastal remote sensing through an interactive global network while Robinson et al. (1993) demonstrated the applications of marine and coastal image data from satellite, airborne and in-situ sensors. Both of the above studies are part of the TREDMAR initiative²². A recently completed project sponsored by UNEP is the GRID Bangkok project which had the mission to provide timely and reliable geo-referenced information addressing environmental issues in Southeast Asia. This project produced a NOAA AVHRR mosaic of Southeast Asia.²³

Recommendation

- **Apply remotely sensed data to assist in planning of aquaculture development.**
Use this information to determine extent of mangrove deforestation

Community based coastal resource management (CB CRM)

Local community-based management of coastal resources or CB CRM places a premium on communities and the central roles they play in resource management. Many of the NGO activities in CB CRM are not recorded and, yet, there is important progress being

²² Marine Sciences Training and Education Program (TREDMAR)

²³ AVHRR: Advanced very high resolution radiometer.

made in the field. CB CRM is an integrated approach to area development. It is holistic in the sense that it needs to resolve conflicts over multiple resource use. Two major factors in CB CRM projects are the rehabilitation, management and conservation of resources; and improvement of the livelihood of local people. CB CRM hence offers a grass roots solution approaching sustainability in the industry.

Recommendation

- **Incorporate community based coastal resource management in the provincial land use plans (i.e. promote integrated area development)**

Achieving compatibility of coastal zone uses

The coastal zone ecosystem needs to be viewed as a system that comprises different components linked together by various ecological processes. Ecosystem-based management techniques consider whether modification or use of any part of the ecosystem can have adverse impacts on all other parts.

Given that industrial activities, urban centers, aquaculture, agriculture and recreation will increase in the future, one of the key requirements would be to ensure compatibility by some form of coastal ecosystem planning. Such a planning approach would greatly benefit the Upper Gulf. The implementation of integrated coastal zone management (ICZM) techniques will take on an ever increasing role in performing such tasks. The need to consider social, environmental and economic objectives in the ecosystem planning will be critical. Solutions that are dominated by an economic benefit may not exhibit long term sustainability.

Needs for environmental information and practical coastal use plans

One of the requirements for coastal land use planning is the availability of systematic and current environmental information. In addition, there are concerns regarding the quality and quantity of data that is collected. Hence, to achieve an acceptable and defensible level of coastal environmental protection a sound knowledge of the physical, chemical and biological processes is required. Monitoring and research programs should be undertaken to find answers to specific resource management problems concerning the

utilization of coastal habitats. An effective water quality management program will be a key part in resolving the issues of compatibility in the coastal zone.

Recommendation

- Consider social, environmental and economic information in planning exercises;

Needs for coordination of research effort

There is an urgent need for practical solutions to problems that threaten the sustainability of the industry. These problems are not related only to business competition, but to various limitations that affect the industry in general. Many of these problems require multidisciplinary investigation by highly qualified personnel working with expensive equipment and facilities. It is not only wasteful for individual companies to duplicate these investigations, but also difficult or even impossible for them to accomplish the work due to limitations in budget and available expertise. Institutions and individuals concerned with this industry must coordinate and focus research efforts to increase the availability of research information relevant to the sustainability of the industry. A summary of the recommendations made by a workshop at the Aquatic Animal Health Research Institute (AAHRI), Bangkok illustrate some of the required actions that should be implemented in order to coordinate research efforts (Table 6.21).

Table 6.21 Summary of recommendations for required actions for coordination of research efforts in shrimp farming in Thailand (Turnbull et al. , 1994)

-
1. Shared, consortium research programs
 2. Specific pathogen-free (SPF) stock production
 3. Genetic improvement program
 4. Health and hygiene program
 5. Environmental programs
 6. Alternative species development program
 7. Broodstock maturation
 8. Husbandry program
 9. Analytical services and pilot-scale wet lab testing
 10. Advisory and training services

Recommendation

- **Coordinate research to avoid duplication of efforts and decrease research efforts which are not sustainable.**

6.7.6 Ecological monitoring systems

BARRIER

Ecological monitoring systems to gather and interpret environmental information, in a useful way, are needed in the Upper Gulf region. Such information is a fundamental requirement of every maritime nation to assess the water quality of its coastal areas. In the case of shrimp farming data on the quality of sea water resources is essential.

Such data is needed to make informed decisions for action towards improving sustainability. Monitoring programs in Thailand, like many other countries, have typically been *ad hoc* and undertaken without coordination. The longevity of measurement programs has, in many cases, coincided with the availability of limited funding. The end result of this approach is a lack of standard methods to collect and organize data which hinders the task of making informed decisions regarding action towards improving sustainability.

SOLUTIONS

As was revealed by the practical participative approach of the fieldwork, complex approaches that are proposed in theoretical approaches may not be the best starting point in Thailand. The failure of the latter approaches to incorporate social, cultural and other factors necessitated the use of the practical participative approach. This approach was essential to making the best interpretation of the environmental information in this case study. In this regard, the challenge and the solutions are quite fundamental.

Development of ecological monitoring systems

The basic question for monitoring is to establish the ecosystem response to human impacts on the environment. To answer this question by ecological monitoring systems the following must be determined: What is happening in the environment? Why is it happening? Why is it significant? and what can we do about it? From the answers to these questions we can establish what should be done about it. Using this approach from the start would improve the design of all ecological monitoring systems in Thailand. Monitoring systems must adopt ecosystem-based approaches using indicators to provide monitoring information that is then evaluated within the context of either risk-based or human and ecosystem well-being. These are cornerstone to establishing ecological monitoring systems. The mechanisms for response to this information barrier are then best applied using government regulations, private sector and community responses.

Recommendations

- **Establish ecological monitoring systems in the context of risk based or human and ecosystem well-being**
- **Improve the design of monitoring systems by determining the appropriate method prior to any data collection (i.e. answer the fundamental questions)**

6.8 Future work on shrimp industry sustainability indicators

Clearly there are many indicators that can be applied to intensive shrimp monoculture systems (Table 6.2). It was beyond the scope of this thesis to explore all of them. However, several indicators will be the focus of future research. The preliminary information regarding these indicators is presented below. They are clearly at the early stage of development in their application to the intensive shrimp culture industry but the information revealed thus far suggest that they will be significant in their usefulness in analyzing the sustainability of the industry.

6.8.1 Suggested future key socioeconomic indicator: consumption levels, equity and over production

Shrimp are produced for the appetites of consumers. An indicator of the unsustainability of the current industry practices is the production and marketing of shrimp products produced at less than full costs. The majority of shrimp produced globally are cultured in ponds located in the coastal environments of developing countries. The negative environmental consequences to produce these shrimp are incurred in these producing countries. At the receiving end, far distant from the shrimp farms, consumers enjoy these products largely unaware of the circumstances under which they were produced. Their consumption is environmentally subsidized.

Equity is another issue. The affordability of shrimp products to the local consumer is also an issue. A 1986 study examined seafood consumption in Japan against income. More seafood, especially shrimp, is consumed by the population with higher income. Thus, the fate of shrimp produced in Thailand is ultimately to furnish the dinner plates of people in Japan, Europe and USA (AMPO: Japan-Asia Quarterly Review, 1987). Preliminary information as to where shrimp are being consumed around the world provide insight as to the consumptive demands driving the export of shrimp from Thailand (Table 6.22). Most of the consumer nations do not contribute to the global production of shrimp products at a level comparable to Asia Pacific.

The consumption indicator highlights the fact that the shrimp are produced for consumers in markets outside of the producing countries. Environmental effects of shrimp farming primarily occur in the producing countries, mostly developing nations. The producing countries are the least equipped to deal with the environmental impacts associated with production. Similarly, the production methods used are illegal in many countries (i.e. untreated discharges, unlicensed operations, use of non-registered pesticides).

Table 6.22 Annual shrimp consumption (lbs/yr) in the major markets, 1993 (Filose, 1995)

United States	800 million pounds*
Japan	700 million pounds
Europe	400 million pounds
Other importers	100 million pounds
Total	2000 million pounds (2.0 billion)

Note: * Imports plus domestic consumption

6.8.2 Suggested future key socioeconomic indicator: rate of investment and investment management

All indications suggest that the overwhelming amounts of investment into aquaculture development in Thailand and other developing countries may have contributed to the pattern of shrimp farm cycle failure. Countries receiving substantial infrastructure development loans have generally been ill-equipped to handle such rapid investment in all its respects. In addition, donor agencies have not imposed requirements for full cost accounting. Recipient countries have been plagued with policy failure, lack of ability to control such rapid developments, and an overall inability to generate suitable land use plans within the existing institutional and regulatory frameworks at short notice. A significant portion of shrimp farming industry problems relate directly to the rate of investment and investment management from major lending institutions like the World Bank (WB) and the Asian Development Bank (ADB).

As this is a future key indicator in the development stage the author will only present figures from the WB and the ADB. In addition, there has been significant investment into shrimp aquaculture in Thailand from other countries (e.g. Taiwan) and other large corporations abroad. Full study of these investments and their part in the shrimp industry was beyond the scope of this thesis. However, the information regarding the WB and the ADB suggest that future study of this future key indicator is warranted.

Major lending institutions like the World Bank (WB) and the Asian Development Bank (ADB) have played significant roles in the expansion of aquaculture throughout Thailand and Southeast Asia. The objective of loans from such agencies has been to provide for 'aquaculture development' to both increase local food production through the culture of farmed shrimp, and to provide foreign export from such products during the 'falling off' in capture fisheries resources.

Table 6.23 indicates the substantial inputs from just the WB. In 1992, the WB invested \$US 1.685 billion in agriculture and fisheries with \$US 425 million alone being given to India's shrimp and fish culture development. Similarly, the ADB's lending activities in 1994 saw around 32 % of the total number of projects being devoted to the agriculture and agro-industry sector for a total value of around \$US 1.6 billion (Anon., 1994e). The

ADB also has a number of technical assistance activities with around 36 % being devoted to the agriculture and agro-industry for a total value of around \$US 330 million (ADB, 1994). Further, the above investments do not take into account government participation in such schemes, nor the substantial and increasing private sector investment.

Table 6.23 Selected statistics of World Bank assistance to the development of coastal shrimp aquaculture production (Modified from Anon., 1994e)

Country	Year	\$US million
Indonesia, Philippines, Thailand, India, and Bangladesh	mid-end 1970's	≈200
China	mid-1980's	600
Brazil	1987	683
China	1988	670
Tunisia and Belize	1988	37.8
China	1989	430
Morocco	1989	190
Indonesia	1989	35.3
Nigeria	1989	400
China	1992	425
India	1992	425
Venezuela	1992	300

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

Intensive shrimp farming in Thailand has developed into a large, and for some, profitable industry. The industry has shown increasing signs of unsustainability including declining productivity and periodic collapses due largely to increased disease and decreased growth rates as a result of environmental degradation. Socio-economic pressures including lack of expertise and unrestricted development have fueled the growth of an industry characterized by high short-term profit and lack of sustainability. Current intensive shrimp culture techniques result in the export of large quantities of dissolved and particulate wastes to the environment. Without treatment these wastes lead to environmental deterioration which may threaten shrimp production and coastal resources, particularly in areas where unrestricted shrimp farming development has occurred, which is the case in virtually in all shrimp farming regions in Thailand.

Focus has now been drawn to the sustainability of aquaculture practices that have caused environmental damage and social disruptions from uncontrolled and unplanned intensive coastal aquaculture development. Principles and standards have yet to be adopted to protect natural resources, ecosystems and human communities.

This research has recognized the need for a complete sustainability assessment of the current Thai shrimp industry. The case study of the Upper Gulf province of Samut Sakhon determined, using quantitative and qualitative methods, that farm cycle failure in the region was attributed to a number of factors. The main factor was determined to be the consistent lack of consideration to the connection between the ecosystem well-being and human well-being. The post abandonment land use responses were indicative of the extent of the damage. The observed responses were reactionary and offered short term solutions in most cases. These responses were viewed as *neutral* or *negative* in terms of sustainability. These factors led to the requirement for a full analysis of the current sustainability of the industry.

An integrated analysis was deemed to be essential to understanding the current situation. Negative trends in the industry were viewed as symptoms of a number of barriers to achieving sustainability. A schematic model for sustainability was then developed to incorporate these factors. Six institutional factors were both viewed as barriers to overcome and opportunities for solutions (Table 1.2). The 'barriers' had been recognized by the negative trends or levels in selected indicators (Table 6.3).

The barriers resulted from the structural or programmatic challenges in the institutional factors. The opportunities for solutions were derived by suggesting changes in these factors. The key indicators selected to reveal the trends in the Thai industry are viewed collectively to reach the conclusion that the Thai industry as it currently operates, was not sustainable (Table 7.1). These indicators are not presented in a priority order. The small base set are considered to be essential trends that need to be monitored in any implementation of a shrimp culture indicator.

Table 7.1 Key indicators: environmental, human and ecosystem health and socioeconomic

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1. **Environmental:** change in habitat/natural areas (mangrove)
 2. **Environmental:** land salinization and land subsidence
 3. **Environmental:** water quality degradation and nutrient and organic enrichment of coastal waters
 4. **Human and ecosystem health:** impacts of farm chemicals on coastal ecosystems
 5. **Socioeconomic:** degree of intensification: production (MT), area cultured (ha) and number of farms/km of coastline

7.2 Recommended changes in institutional factors

The final recommendations of this research follow directly from the solutions proposed in the sustainability analysis of Section 6.7 where they are highlighted in bold. Each recommendation has been inserted in Chapter 6 at the point where the discussion and reasons for advancing the proposed solutions have been made. For ready reference, the page citations have been included. The recommendations in this section need to be further assessed considering the following factors: relevance, priority, cost and feasibility. Such an analysis is beyond the scope of this thesis. Therefore, the order of presentation of the recommendations is not meant to infer that the above factors have been considered. They are to be viewed collectively. The recommendations are presented under the institutional factor headings that were used as the framework for the analysis conducted in Chapter 6.

Economic

- Apply full cost-benefit analysis to all aquaculture developments to incorporate ecological and ecological externalities (i.e. pay full environmental costs) - p. 185
- Improve the food allocation to local consumers by export reorientation - p. 186
- Improve resource allocation for agro- and aqua- based commodities - p. 186
- Increase the accountability of lending institutions and improve the focus of investment - p. 188
- Reduce the rate and concentration of investment capital - p. 186
- Inform and educate consumers as to the level of biophysical resource appropriation (and the resulting environmental impacts) required to support the shrimp farming effort. There is a large ecological deficit - p. 186
- Initiate studies on the macro-economic and social feasibility of intensive monoculture systems - p. 184

Science and Technological Innovation

- Rethink pond management practices to reduce pollution, reduce risk of disease and improve farm cycle performance through control of chemical use, reduction of stocking densities and improved control of feed inputs - p. 192
- Educate farmers as to the potential damaging effects of continued over prescription of harmful chemicals (i.e. chloramphenicol). Chemicals are not effective and do not improve farm performance - p. 192
- Improve shrimp farm system design to incorporate resource recovery techniques - p. 194
- Develop protocols to limit establishing excessive production capacities which exceed carrying capacity of the receiving environment - p. 193
- Increase presence of regulatory and other personnel in shrimp farming areas to introduce and discuss land use plans and low-risk aquaculture systems (i.e. lower intensity, incorporate life cycle design methods) - p. 193
- Improve site selection factors, incorporate feasibility studies and promote inter-farm cooperation with water systems - p. 193
- Promote the application of ecologically integrated systems and methods (physical, biological) - p. 200
- Implement and enforce pro-conservation laws, consider reforestation in abandoned areas - p. 202

- Research the prospect of using mangrove-aquaculture systems to treat effluent by replanting or using buffer zones close to shrimp ponds - p. 203
- Continue trials of "closed culture systems" and further refine end use disposal methods for harvest effluent from closed systems - p. 202

Institutional Structures

- Increase inter-sectoral cooperation between the DOF and the Royal Forestry Department on mangrove afforestation in abandoned areas - p. 206
- Recognize the interconnectedness of ecosystems. Incorporate ecosystem based management concepts in agencies with the power to intervene in the different parts of the ecosystem (i.e. decrease segregation of the coastal zone) - p. 207
- Strengthen the powers of the environmental protection agencies within the current power structure (increased capacity to act) - p. 209
- Incorporate the requirement for capacity building in loans to aquaculture development - p. 207
- Increase the involvement of NGO's in decisions. Recognize that they have direct experience in dealing with the environmental impacts - p. 208
- Industry must accept that the preferences of consumers may influence future product desirability. Incorporate the changes to their operations prior to this event - p. 208
- Improve import and export testing of all shrimp products. Accurate information regarding quality and safety is lacking - p. 208

Policies and legislation

- Determine practical methods of enforcing the standards. Make them achievable to small scale operators and punish larger scale operations for breaking the law - p. 215
- Increase accountability of operators for environmental damages (reverse onus on potential developers) - p. 214

Planning and information systems

- Apply ecological risk assessment techniques in all shrimp farm developments- p. 216
- Incorporate environmental management systems in accordance with ISO 14000 - p.217
- Utilize GPS in environmental protection applications (i.e. marking out the mangrove conservation areas and determining where illegal farms are located) - p. 217

- Apply remotely sensed data to assist in planning of aquaculture development. Use this information to determine extent of mangrove deforestation - p. 219
- Incorporate community based coastal resource management in the provincial land use plans (i.e. promote integrated area development) - p. 220
- Consider social, environmental and economic information in planning exercises - p. 221
- Coordinate research to avoid duplication of efforts and decrease research efforts which are not sustainable - p. 222

Ecological Monitoring Systems

- Establish ecological monitoring systems in the context of risk based or human and ecosystem well-being - p. 223
- Improve the design of monitoring systems by determining the appropriate method prior to any data collection (i.e. answer the fundamental questions) - p. 223

It is suggested that if these recommendations can be implemented in combination with the information gathered from the key indicators, the sustainability of Thai shrimp farming industry would improve. Evidence suggests that a more sustainable approach is urgently required. Failure to make this application, however, may result in further declines in the overall sustainability and ultimately the repeated collapse of shrimp farming operations. In seeking to meet the overall objective of achieving sustainability, it is important to emphasize the importance of maintaining human and ecosystem well-being, as central themes in the implementation of the proposed recommendations.

7.3 Contributions of the study

By conducting a thorough biophysical survey, and applying those results in a sustainability assessment, this study has demonstrated that the shrimp farming industry in Thailand does not currently operate to ensure long term ecosystem and human well-being. The current practices have raised critical questions concerning ecological impacts, socioeconomic effects and human/ecosystem health concerns that have been thoroughly documented in this thesis. Studies prior to this work, undertaken using single disciplinary approaches, have not integrated economic, social and environmental factors in identifying barriers and proposing solutions. This work has begun that process of integration.

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Appendix A: Relevant Thai standards (for sea water, surface, aquaculture and river water quality) and other suitability and toxicity established values of contaminants related to aquaculture.

Table A.1 Thai standards for sea water quality (ONEB, 1991)

Water Quality	Type of coastal water		
	1: Nature conservation	2: Coral conservation	3: Other natural resources
Industrial Zone			
Water Quality Unit			
Floatable solids	NR	NDt	NDt
Floatable oil and grease	NR	unseen	unseen
Color and Odor	NR	-	-
Water temperature (°C)	NR	not > 33	not > 33
pH	NR	7.5-8.9	7.0-8.5
Salinity (ppt)	NR	29-35	NC >10 %
Transparency (m)	NR	NC >10 %	NC >10 %
DO (mg/L)	NR	not <4	not <4
Total coliform bacteria (MPN/100 mL)	NR	-	-
Fecal coliform bacteria (MPN/100 mL)	NR	-	-
NO ₃ -N (mg/L)	NR	NR	NR
PO ₄ -P (mg/L)	NR	NR	NR
Total Hg (mg/L)	NR	not>0.0001	not>0.0001
Cd (mg/L)	NR	not>0.005	not>0.005
Cr (mg/L)	NR	not>0.1	not>0.1
Cr Hexavalent (mg/L)	NR	not>0.05	not>0.05
Pb (mg/L)	NR	not>0.05	not>0.05
Cu (mg/L)	NR	not>0.05	not>0.05
Mn (mg/L)	NR	not>0.1	not>0.1
Zn (mg/L)	NR	not>0.1	not>0.1
Fe (mg/L)	NR	not>0.3	not>0.3
F (mg/L)	NR	not>1.5	not>1.5
Residual Cl (mg/L)	NR	not>0.01	not>0.01
Phenol (mg/L)	NR	not>0.03	not>0.03
NH ₃ -N (mg/L)	NR	not>0.4	not>0.4
Sulfide (mg/L)	NR	not>0.01	not>0.01
CN (mg/L)	NR	not>0.01	not>0.01
PCB (mg/L)	NR	NR	NR
Total Organochlorine Pesticides (µg/L)	NR	not>0.05	not>0.05
Radioactivity (Bq/L)	NR		
Alpha-Gross (Bq/L)		not>0.1	not>0.1
Beta-Gross (Bq/L)		not>1.0	not>1.0

Note: NR=Natural; NDt = Not detectable; NC = No change from the natural condition; ** = Will be assigned as necessary; not > = not more than; not < = not less than

Table A.1 Thai standards for sea water quality (ONEB, 1991) (continued)

Water Quality Industrial Zone	Type of Coastal Water			
	4: coastal aquaculture	5: swimming	6: other water sports	7: for water sports
Water Quality Unit				
Floatable solids	NDt	NDt	NDt	NDt
Floatable oil and grease	unseen	unseen	unseen	unseen
Color and Odor	NDt	NDt	NDt	NDt
Water temperature (°C)	not > 33	-	-	not > 33
pH	7.0-8.5	-	-	**
Salinity (ppt)	NC >10 %	-	-	**
Transparency (m)	NC >10 %	NC >10 %	-	**
DO (mg/L)	not <4	-	-	**
Total coliform bacteria (MPN/100 mL)	not >1000	not >1000	-	-
Fecal coliform bacteria (MPN/100 mL)	NR	-	-	-
NO ₃ -N (mg/L)	-	-	-	**
PO ₄ -P (mg/L)	-	-	-	**
Total Hg (mg/L)	not>0.0001	-	-	not>0.0001
Cd (mg/L)	not>0.005	-	-	not>0.005
Cr (mg/L)	not >0.1	-	-	**
Cr Hexavalent (mg/L)	not>0.05	-	-	not>0.1
Pb (mg/L)	not>0.05	-	-	**
Cu (mg/L)	not>0.05	-	-	**
Mn (mg/L)	not>0.1	-	-	**
Zn (mg/L)	not>0.1	-	-	**
Fe (mg/L)	not>0.3	-	-	**
F (mg/L)	not>1.5	-	-	**
Residual Cl (mg/L)	not>0.10	-	-	**
Phenol (mg/L)	not>0.03	-	-	**
NH ₃ -N (mg/L)	not>0.4	-	-	**
Sulfide (mg/L)	not>0.01	-	-	**
CN (mg/L)	not>0.01	-	-	**
PCB (mg/L)	NR	-	-	**
Total Organochlorine	not>0.05	-	-	**
Pesticides (µg/L)				
Radioactivity (Bq/L)		-	-	**
Alpha-Gross (Bq/L)	not>0.1			
Beta-Gross (Bq/L)	not>1.0			

Note: NR = Natural; NDt = Not detectable; NC = No change from the natural condition;
 ** = Will be assigned as necessary; not > = not more than; not < = not less than

Table A.2 Thai surface water classification

Class	Objectives/condition and beneficial use
1	Extra clean fresh water surface water resources used for: (1) conservation, not necessary passed through water treatment processes; require only ordinary process for pathogenic destruction; and (2) ecosystem conservation which basic living organisms can spread breeding naturally
2	Very clean fresh surface water resources used for: (1) consumption which require the ordinary water treatment process before use; (2) aquatic organism conservation for living and assisting for fishery; (3) fishery; and (4) recreation
3	Medium clean fresh surface water resource used for: (1) consumption but have to pass through an ordinary treatment process before use; and (2) agriculture
4	Fairly clean fresh surface water resources used for: (1) consumption but require special treatment process before use; (2) industry; and (3) other activities
5	The resources which are not classified in class 1-4 are used for: (1) navigation

Note: Notification of the Ministry of Science, Technology and Energy in 1985 and published in Royal Government Gazette, Vol. 103, Part 60, dated April 15, 1986.

Table A.3 Thai water quality standard for coastal aquaculture (ONEB, 1991)

Determinant	Level
Floatable solids; Floatable oil and grease	not visual noticeable
Color and odor	not visual noticeable
Water temperature	not above 33° C
pH	7.0-8.5
Salinity	not above or below 10 % of normal value
Transparency	not above or below 10 % of normal value
Dissolved Oxygen	4 mg/L
Total Coliform bacteria	not above 1000 MPN/100 mL
Fecal Coliform bacteria	not above normal value
Total mercury	not above 0.0001 mg
Cadmium	not above 0.005
Chromium	not above 0.1
Chromium hexavalent	not above 0.05
Copper; Lead	not above 0.05
Manganese; Zinc	not above 0.01
Iron	not above 0.03
Fluorine	not above 1.5
Residual chlorine	not above 0.01
Phenols	not above 0.03
Ammonia-nitrogen	not above 0.4
Sulfide	not above 0.01
Cyanide	not above 0.01
Poly chlorinated biphenyl	not above normal value
Total organic-chlorine pesticides	not above 0.05 µg/L
Alpha radioactivity	not above 0.1
Total Beta radioactivity	not above 1.0

Table A.4 River water quality standards for the Chao Phraya and Thachin rivers

Control Areas (km from river mouth)	Water Quality Standards (according to standard of water classification)
Chao Phraya*	
7-62	Class 4
62-142	Class 3
142-379	Class 2
Thachin**	
0-82	Class 4
82-202	Class 3
202-325	Class 2

* Notification of the Office of the National Environment Board, January 17, B.E. 2529 (1986), published in the Royal Government Gazette, Vol. 103, No. 60, dated April 15, B.E. 2529 (1986).

** Proposed by the Sub-Committee of Thachin River Management under the Environmental Committee on Water, approved by the National Environment Board, May 28 B.E. 2529 (1986). To be issued under the National Environmental Quality Act.

Table A.5 Suitable levels for selected environmental parameters important for operation of intensive shrimp aquaculture farms

DO (ppm)	> 5
pH	8.0 to 8.5
Hardness	20-200 ppm as CaCO
Temperature (°C)	28 to 33
Carbon dioxide (ppm)	2.0
Copper (ppm)	0.1 (<0.006 ppm soft water)
Iron (ppm)	1.0
Mercury, Chromium (ppm)	0.05
Lead (ppm)	0.03
Cadmium (ppb)	3.0
Unionized ammonia (NH ₃) (ppm)	0.1
Nitrite (ppm)	0.25
Nitrogen (%)	110
Hydrogen sulfide (ppm)	0.02
Salinity (ppt)	15-25
Transparency (cm)	20-70
Depth of water (cm)	60-150

Table A.6 Toxicity of heavy metals to a variety of species of freshwater and marine animals from various publications (Boyd, 1989)

Metal	Range of 96-hr LC-50 * ($\mu\text{g/L}$)	Safe level recommended by USEPA ($\mu\text{g/L}$)
Cadmium	80-420	0
Chromium	2 000-20,000	100
Copper	300-1,000	25
Lead	1,000- 40,000	100
Mercury	10-40	0.10
Zinc	1,000-10,000	100

* The 96-hr LC-50 is the concentration of a substance which will kill 50 % of the organisms in a laboratory toxicity test within 96-hr exposure time.

Table A.7 Median international standards and ranges in such standards ($\mu\text{g/g}$ wet weight) for trace elements in freshwater and marine fish and shellfish (Nauen, 1983)

Element	Median standards			Number of countries with standards
	Fish	Shellfish	Range	
Antimony	1.0	1.0	1.0-1.5	3
Arsenic	1.5	1.4	0.1-5.0	11
Cadmium	0.3	1.0	0.05-2.0	10
Chromium	1.0	1.0	1.0	1
Copper	20	20	10 to 100	8
Fluoride	150	-	150	1
Fluorine	17.5	-	10-25	2
Lead	2.0	2.0	0.5-10	19
Mercury	0.5	0.5	0.1-1.0	28
Selenium	2.0	0.3	0.3-2.0	3
Tin	150.0	190.0	50-250	8
Zinc	45	70	40-100	6

Table A.8 For pesticides in water, the following safe levels ($\mu\text{g/L}$) were suggested for shrimp (Modified from Chen, 1985; Tseng, 1987; Boyd, 1989)

Aldrin/Dieldrin	0.003
Azodrin; Chlordane; Endosulfan; Paraquat	0.01
BHC	4
Butschlor	1.0
DDT; Heptachlor; Malathion	0.001
Endrin	0.004
Parathion	0.0004
Rotenone	0.008
Saturn	0.033
Toxapane	0.005

Table A.9 Toxicity comparisons between some selected pesticides to some freshwater and marine animals (Phillips *et al.*, 1993; Boyd, 1989)

Compound	Level ($\mu\text{g/L}$)	Period	Mortality effect (LC50)	Species
Aldrin/dieldrin	0.20-16	96 hr	50 %	not specified
BHC	0.17-240	96 hr	50 %	not specified
Chlordane	5-3000	96 hr	50 %	not specified
DDT	0.24-2	96 hr	50 %	not specified
	0.1	8 days	mortality	<i>P. setiferus</i>
	>0.1	28 days	mortality	<i>P. duorarum</i>
Diazonin	4.8	96 hr	50 %	<i>Mysidopsis bahia</i>
	28.0	96 hr	50 %	<i>P. aztecus</i>
Dibrom	2.0	48 hr	50 %	<i>P. aztecus</i> PL's
	5.5	48 hr	50 %	<i>P. aztecus</i> adult
Dieldrin	0.9	96 hr	50 %	<i>P. aztecus</i>
Endrin	0.13-12	96 hr	50 %	not specified
Heptachlor	0.10-230	96 hr	50 %	not specified
	0.11	96 hr	50 %	<i>P. duorarum</i>
Toxapane	1-6	96 hr	50 %	not specified
Metamidophos	0.011	24 hr	50 %	<i>P. stlirostris</i> nauplii
Parathion	0.2	48 hr	mortality	<i>P. duorarum</i>

Table A.10 Non--registered pesticides in Thailand detected in the central region province of Samut Sakhon by the author's field investigation

Compound	Effective Date	Remark
DDT	4 March 1983	*
Dieldrin	16 May 1988	*
Aldrin	23 September 1988	*
Heptachlor	23 September 1988	*

Note: organochlorine pesticide

Appendix B: Comparative data for Chapter Five discussion

Table B.1 Comparison of physical and chemical parameters pond water quality of two culture systems in Ranot, and Songkhla, Thailand (Kanit *et al.*, 1992)

Parameter	System 1*		System 2**	
	Range	Average	Range	Average
Physical				
Secchi Disk Depth (cm)	17-54.7	33	27.7-57.5	40.8
Depth (cm)	100-160	131	120-150	132
Temperature (°C)	28.2-32.3	30.2	28-31.4	29.4
Chemical				
Salinity (ppt)	22.2-35	31.1	29.6-34.7	32.5
pH	7.5-8.4	8	7.8-8.3	8
DO (mg/L)	3.8-8.7	7.2	6.2-8.2	7.3

* System 1 = stocking density of 25 pieces per square meter

** System 2 = stocking density of 64 pieces per square meter

Table B.2 Comparison of inorganic contaminant pond water quality parameters of two culture systems in Ranot, Songkhla (Kanit *et al.*, 1992)

Parameter	System 1*		System 2**	
	Range	Average	Range	Average
Nitrate (mg/L)	0.012-0.125	0.037	0.006-0.031	0.16
Nitrite (mg/L)	0.001-0.07	0.013	0.001-0.009	0.003
Ammonia (mg/L)	0.065-1.647	0.612	0.011-0.338	0.106
Orthophosphate (mg/L)	0.003-0.312	0.025	0.001-0.025	0.009
BOD (mg/L)	3.4-11.4	7.1	2-10.5	5.4
Suspended solid (mg/L)	138-354.5	213.9	137.8-233.7	184.4
Chlorophyll <i>a</i> (µg/L)	41.4-339.2	140.1	37.4-153.2	75.7

* System 1 = stocking density of 25 pieces per square meter

** System 2 = stocking density of 64 pieces per square meter

Table B.3 Water quality of shrimp pond with a low stocking density (25 pieces/m²) from 14 October 1991 to 15 December 1992 (Kanit and Songsangjinda, 1992)

	2nd week	4th week	6th week	8th week	10th week	12th week	14th week	16th week	18th week
Depth (cm)	90-120 109	114-125 121	120-126 123	118-134 127	110-140 123	120-142 136	120-140 134	130-150 139	100-145 122
T (°C)	29.3-33.1 30.8	28.1-29.3 28.6	27.7-29.8 28.6	27.1-29.5 28.1	30-31.4 30.6	27.3-31.7 29	29.7-31 30.3	27.2-30.5 28.4	25.7-28 27.3
DO (mg/L)	6.7-9.8 8.1	6-7 6.6	5-6.3 5.9	3.9-7.4 5.9	5.6-7.9 7	6.3-7.2 6.3	7.1-11.5 8.7	6.6-8.4 7.6	6.9-8.1 7
pH	7.88-8.64 8.2	8.2-8.56 8.35	7.92-8.42 8.08	7.9-8.56 8.17	7.74-8.5 8.15	7.52-8.09 7.77	7.15-8.01 7.77	7.65-8 7.78	7.27-7.67 7.49
Salinity (ppt)	34-38 37	36-40 39	34-38 37	27-36 32	33-37 35	30-33 31	30-35 32	26-31 29	26-28 27
Secchi disk (cm)	47-75 63	58-75 70	52-100 73	45-56 53	34-70 50	35-55 43	36-53 41	31-56 41	24-54 33
Nitrite (mg/L)	0-0 0	0-0.02 0.01	0-0.01 0	0-0 0	0-0 0	0-0 0	0-0.01 0	0-0.12 0.02	0-0.01 0
Nitrate (mg/L)	0-0.02 0.01	0.01-0.05 0.02	0-0.07 0.02	0-0.02 0.01	0.01-0.04 0.02	0-0.04 0.02	0-0.02 0.01	0-0.2 0.05	0-0.02 0.01
NH ₄ (mg/L)	0-0.11 0.05	0-0.04 0.02	0-0.25 0.05	0-0.02 0.01	0-0.58 0.17	0.01-0.7 0.39	0-0.94 0.16	0-0.6 0.15	0.01-0.87 0.3
PO ₄ (mg/L)	0-0.01 0	0-0.01 0.01	0-0.02 0.01	0-0.01 0	0-0.01 0	0-0.02 0.01	0-0.02 0.01	0-0.02 0.01	0-0.01 0
BOD (mg/L)	1.38-7.98 4.02	3.66-6.9 4.75	2.46-4.62 3.28	2.16-4.8 3.51	1.29-7.05 4.42	2.19-6.54 4.17	1.14-6.78 4.35	4.26-7.5 6.06	5.22-12.54 8.82
TSS (mg/L)	144-197 177	150-182 163.5	125-166 146	112-186 138	111-165 141	101-165 139	131-257 184	112-216 172	135-215 186
Chl a (µg/l)	11.76-34.9 21.74	7.52-109.49 42.53	16.21-84.85 40.27	27.26-51.6 39.74	35.18-88.88 86.07	39.43-135.69 64.16	81.58-142.27 109.24	95.36-210.07 162.3	51.8-148.72 112.46

Table B.4 Water quality of a shrimp pond with high shrimp stocking density (64 pieces/m²) from 14 October 1991 to 15 December 1992 (Kanit et al., 1992)

	2nd week	4th week	6th week	8th week	10th week	12th week	14th week	16th week	18th week
Depth (cm)	80-110 (94)	109- 120 (114)	120- 130 (128)	120- 130 (128)	110- 180 (135)	130- 150 (139)	110- 150 (132)	110- 140 (132)	130- 150 (140)
T(°C)	27.3- 31 29.3	33.3- 27.9 29.8	24.3- 32.1 29.1	27.3- 31.8 30.6	27.8- 32.5 30.5	26.8- 32.5 29	27.3- 30 28.8	27.3- 30 28.8	28.6- 29.1 28.9
DO (mg/L)	5.6-9.9 6.9	3.5-7.8 6.5	6.4- 10.5 7.7	5.4-9.8 7.6	5.7- 13.5 8.8	4.4- 11.1 8	7.5-8.8 8.1	7.5-8.8 8.1	7.2-8 7.6
pH	7.72- 8.6 8.18	6.25- 8.95 8.05	7.58- 8.36 8.04	7.33- 8.4 8.01	7.28- 8.48 7.86	7.09- 8.6 7.6	7.2-8.2 7.68	7.2-8.2 7.68	6.98- 7.4 7.19
Salinity (ppt)	35-40 37	35-42 37	28-37 33	29-39 33	29-37 32	25-31 29	15-31 24	15-31 24	31-33 32
Secchi disk (cm)	33-80 55	30-75 49	28-47 37	32.81 41	20-37 30	24-47 34	24-34 28	24-34 28	28-35 32
Nitrite (mg/L)	0-0 0	0-0.03 0.01	0-0.03 0.01	0-0.01 0	0-0.02 0	0-0.02 0.01	0-0.02 0.01	0-0.02 0.01	0-0.04 0.02
Nitrate (mg/L)	0-0.02 0.01	0.01- 0.09 0.04	0-0.13 0.02	0-0.04 0.02	0-0.04 0.02	0.01- 0.08 0.03	0.01- 0.05 0.03	0.01- 0.05 0.03	0.02- 0.09 0.05
NH ₄ (mg/L)	0-0.44 0.08	0.02- 0.48 0.12	0-0.65 0.16	0-1.42 0.43	0-2.05 0.49	0-2.98 1.01	0.25- 3.84 2.16	0.25- 3.84 2.16	0.17- 3.31 1.74
Phosph ate (mg/L)	0-0.04 0.01	0-0.18 0.03	0-0.01 0	0-0.02 0.01	0-0.02 0.01	0-0.04 0.01	0-0.02 0.01	0-0.02 0.01	0.01- 0.03
BOD (mg/L)	1.68- 11.22 5.71	1.44- 13.92 7.96	3.84- 11.94 7.55	1.02- 11.67 7.09	5.7- 17.94 9.81	5.88- 13.29 7.9	5.88- 17.82 11.14	5.88- 17.82 11.14	8.34- 8.76 8.55
TSS (mg/L)	115- 239 163	24-226 132	94-225 162	136- 185 161	143- 191 162	126- 178 156	109- 260 176.5	109- 260 176.5	168- 168 168
Chl a (µg/l)	10.08- 127.41 47.96	24.91- 77.6 52.63	33.81- 235.87 126.91	55.22- 164.82 116.35	113.65 - 411.22 241.88	86.96- 343.61 - 211.68	186.64 - 409.28 294.45	186.64 - 409.28 294.45	179.34 - 290.61 234.96

Table B.5 Water quality of sea water resources for shrimp farming in 1992 excluding Samut Sakhon (Modified from FAO/NACA, 1995)

Province	Surat Thani	Prachuab Kiri Khan		Chachoengsao
Location	Mouth of Tha Thong	Bang Nang Rom	Wan	Bang Pakong River Mouth
Salinity (ppt)	0.0-30.5	28-34	32-35	0.0-32
pH	5.1-8.2	7.4-8.4	7.4-8.2	6.7-8.0
DO (mg/L)	2.8-11.2	3.3-11.7	4.3-9.2	4.1-8.8
BOD (mg/L)	0.8-7.7	ND	ND	ND
Nitrite (mg/L)	0.002-0.022	0.007-0.481	0.002-0.071	0.005-0.122
Ammonia (mg/L)	0.001-0.948	0.000-0.475	0.000-0.302	0.072-0.702
Phosphate (mg/L)	0.00-0.591	0.008-0.481	0.05-0.42	0.00-0.05

Note: All of the above are canals except for Chachoengsao province.

Table B.6 Water quality of the lower Thachin in 1990 (Somsiri *et. al.*, 1990)

Parameter	Range
pH	7.22-7.34
DO (mg/L)	1.20-4.0
Water Temperature (°C)	29.4-31.63
CO ₂ (mg/L)	12.10-23.63
Hardness (mg/L)	127.34-187.00
Alkalinity (mg/L)	154.00-214.75
BOD (mg/L)	3.50-3.87
COD (mg/L)	34.50-230.00
NO ₃ -N (mg/L) (Nitrate-Nitrogen)	0.21-1.32
NO ₂ -N (mg/L) (Nitrite-Nitrogen)	0.03-0.09
NH ₃ -N (mg/L)	0.18-0.50
PO ₄ -P (mg/L)	0.14-0.17

Table B.7 Level (mg/L) of heavy metals detected in the main estuaries of the Gulf of Thailand region (Anat *et. al.* 1987)

Estuaries		Pb	Zn	Cu	Cd	Hg
Thachin	Avg.	10.72	3.44	17.11	1.91	0.24
	Min.	6.50	0.11	2.70	0.90	0.10
	Max.	22.00	14.50	94.00	2.45	0.50
Mae Klong	Avg.	9.65	6.76	22.96	2.01	0.38
	Min.	4.00	0.10	3.10	1.10	0.08
	Max.	24.00	25.00	150.00	2.55	1.25
Phetchaburi	Avg.	11.97	3.13	14.61	2.01	0.27
	Min.	3.50	0.08	3.20	1.15	0.08
	Max.	28.00	12.50	94.00	2.55	0.88
Bang Pakong	Avg.	11.78	2.20	27.14	1.88	0.30
	Min.	4.00	0.07	2.00	1.20	0.10
	Max.	26.00	10.57	124.00	2.35	1.24
Prachinburi	Avg.	11.00	4.29	19.52	1.94	0.28
	Min.	6.00	0.17	1.00	0.75	0.08
	Max.	24.00	28.00	160.00	2.50	0.12
ONEB river standard		50.00	1,000	100.00	5.0-50	2.00

Table B.8 Amount of heavy metal residues in the water of Thachin river in January, 1990 (Coastal Aquaculture Division, DOE, 1993)

Location	Lead	Cadmium	Copper	Zinc
Upper part	0.04	0.02	0.04	0.31
Middle part	0.06	0.03	0.03	0.29
Mouth of River	0.12	0.05	0.10	0.33

Table B.9 Heavy metals in Chao Phraya river in 1984 (Onodera, 1985)

Metals	River water ($\mu\text{g/L}$)		Standard ($\mu\text{g/L}$)
	Average	Range	
Cu	16.0	4.81-66.9	100
Ni	18.6	2.75-137	100
Pb	2.07	ND-4.05	50
Cd	2.52	ND-4.29	5-50
Total Hg	<0.2	ND-0.43	2

Note: ND = Non-detectable

Table B.10 Level of metal in shrimp pond effluent in southern Thailand for Hua Sai and Ranot in 1993 (OEPP, 1994a)

Metal	Shrimp pond	Effluent
Aluminum (mg/L)	1.12	2.64
Copper (mg/L)	0.05	0.05
Iron (mg/L)	1.17	1.92
Lead (mg/L)	0.03	0.03
Manganese (mg/L)	0.23	0.9
Mercury (mg/L)	0.001	0.001
Potassium (mg/L)	81.3	92.7
Magnesium (%)	0.13	0.12

Table B.11 Level (mg/L) of heavy metals detected in ground water in Thailand (Ground Water Division, Bangkok, 1985)

Metal	Year			Drinking water standard	
	1982	1983	1985		
Cu	ND-0.13 (0.007)	ND-0.25 (0.0033)	ND-0.12 (0.0021)	1.0 (1)	1.5 (2)
Zn	ND-19.0 (0.333)	ND-8.4 (0.380)	ND-8.8 (0.284)	5.0 (1)	15.0 (2)
Mn	ND-22.0 (0.389)	ND-7.4 (0.376)	ND-6.7 (0.297)	0.3 (1)	0.5 (2)

Note: ND = non-detectable; Figures in parenthesis are average values
(1) = highest desirable level; (2) = maximum permissible level.

Table B.12 Planktonic organisms found in intensive shrimp culture ponds in Hua Sai from 14 August 1991 to 16 December 1992 (Kanit *et. al.*, 1991)

Phylum	Family	No.	Species	
Phytoplankton Cyanophyta (Blue green algae)	Chroococcaceae	1	Chroococcus	
		2	Coelosphaerium	
	Nostocaceae	3	Polycystis	
		4	Anabaena	
		5	Nostoc	
		Oscillatoriaceae	6	Lyngbya
			7	Oscillatoria
		8	Phormidium	
		9	Spirulina	
		10	Trichodesmium	
Chlorophyta (Green algae)	Chlorococcaceae	11	Chlorococcum	
	Desmidiaceae	12	Closterium	
		13	Staurastrum	
		14	Cosmarium	
		15	Macractinium	
	Macractiniaceae	16	Chlorella	
	Oocystaceae	17	Ankistrodesmus	
	Scenedesmaceae	18	Scenedesmus	
	Volvocidae	19	Gonium	
		20	Pandorina	
	Zygnemataceae	21	Spirogyra	
Bacillariophyta (Diatom)	Bacteriastraceae	22	Bacteriastrum	
	Biddulphiaceae	23	Biddulphia	
		24	Ditylum	
		25	Hemiaulus	
		26	Triceratium	
		Chaetoceraceae	27	Cheatocherus
		Corethronaceae	28	Guinadia
		Coscinodiscaceae	29	Actinophyschus
			30	Coscinodiscus
			31	Cyclotella
		Eucampiaceae	32	Climacodium
	33		Eucampia	
	34		Streptotheca	
	Fragilariaceae		35	Asterionella
		36	Fragillaria	
		37	Synedra	
		38	Thalassionema	
		39	Thalassiothrix	
	Pleurochloridaceae	40	Botrydiopsis	
	Melosiraceae	41	Melosira	
	Naviculaceae	42	Ampiphora	
43		Amphora		
44		Gyrosigma		
45		Navicula		

Table B.12 Planktonic organisms found in intensive shrimp culture ponds in Hua Sai from 14 August 1991 to 16 December 1992 (Kanit *et. al.* 1991) (continued)

Phylum	Family	No.	Species
		46	Pleurosigma
		47	Trachyneis aspera
	Nitzschiaceae	48	Nitzschia
	Rhizosoleniaceae	49	Rhizosolenia
	Skeletonemaceae	50	Skeletonema
		51	Stephanopyxis
	Surirellaceae	52	Campylodiscus
		53	Surirella
	Dictyochaceae	54	Dictyocha
Pyrrophyta (Dinoflagellata)	Peridiniidae	55	Geratium
		56	Gymnodinium lohmanni
		57	Gymnodinium
		58	Peridinium
Euglenophyta	Euglenidae	59	Euglena
Zooplankton	Ciliate	60	unknown ciliate
Protozoa	Codonellidae	61	Tintinnopsis
	Cymbaloporidae	62	Treptomphalus
	Diffugiidae	63	Diffugia
	Globigerinidae	64	Globigerina
	Parameciidae	65	Paramecium
	Ptyochocylidae	66	Favella
	Scyphididae	67	Scyphidium
	Tintinnididae	68	Tintinnidium
	Vorticellidae	69	Vorticella
		70	Zoothamnium
		71	Dictyocha
	Xystonellidae	72	Xystonella
Coelenterata	-	73	Hydrozoa
Arthropoda	-	74	Balanus
	-	75	Ostracod
	-	76	Copepod
	-	77	Shrimp larva
	Daphnidae	78	Daphnia
Rotifera	-	79	Rotifer
Mollusca	-	80	Gastropod larvae
	-	81	Bivalve larvae
-	-	82	Nematode
-	-	83	Polychaete
-	-	84	Fish larva

Appendix C: Summary of plankton sampling information from December 7th, 1994 to April 5th, 1995 collected from 3 locations in the province of Samut Sakhon, Thailand

Table C.1 Enumeration (cells/liter) of plankton samples by phylum, family and species collected in Samut Sakhon province at Station 1: Pitthayalongkorn Canal from 7 December 1994 to 5 April 1995

Phylum	Family	Species	Number (cells/L)
PHYTOPLANKTON			
Cyanophyta (Blue green algae)	Oscillatoriaceae	Oscillatoria	75 (S3)
Chlorophyta (Green algae)			
Bacillariophyta (Diatoms)	Bacteriastreae	Bacteriastrum	120(S1); 75 (S3); 100 (S6)
	Biddulphiaceae	Cyclotella Biddulphia	95 (S1); 975 (S3); 250 (S4); 1,000 (S5); 2,200 (S6); 375 (S7); 500 (S8)
	Chaetoceraeae	Chaetoceros	3,480 (S1); 225 (S3); 6,375 (S4); 300 (S-6)
	Coscinodiscaceae	Coscinodiscus	1,050 (S3); 375 (S4); 50 (S5); 1,300 (S6); 375 (S7); 625 (S8)
	Eucampiaceae	Eucampia Lauderia	3,480 (S1) 2,880 (S1)
	Melosiraceae	Melosira	120 (S1);
	Naviculaceae	Navicula Ampiphora Amphora	120 (S1); 250 (S8) 200 (S6) 650 (S5)
	Pleurochloridaceae	Pleurosigma	3,000 (S1); 975 (S3); 625 (S4); 9,200 (S5); 3,200 (S6); 750 (S7); 750 (S8)
	Nitzschiaceae	Nitzschia	6,000 (S1); 190 (S2); 4,950 (S3); 1,875 (S4); 8,400 (S5); 5,600 (S6); 1,500 (S7); 1,625 (S8)
	Rhizosoleniaceae	Rhizosolenia	2,250 (S1); 100 (S6)
	Skeletonemaceae	Skeletonema	16,800 (S5); 500 (S6); 2,125 (S7); 375 (S8)
	Surirellaceae	Surirella	150 (S3); 100 (S6)
Pyrrophyta (Dinoflagellata)	Peridiniidae	Peridinium	125(S4)
		Noctiluca Ceratum Dinophysis	600 (S1); 500 (S4); 125 (S8) 125 (S4) 125 (S4)
Euglenophyta (Euglenoids)			
Zooplankton			
Protozoa	Tintinnididae	Tintinnopsis	190 (S1); 1,800 (S3); 375 (S4); 1,150 (S5); 4,100 (S6); 375 (S7)
Coelenterata	-		
Arthropoda	-	Copepod	1,440 (S1); 95 (S2); 300 (S3); 625 (S4); 400 (S5) 400 (S6)

Notes:

1. S1 (7-Dec-94); S2 (12-Jan-95); S3 (26-Jan-95); S4 (9-Feb-95); S5 (23-Feb-95); S6 (9-Mar-95); S7 (23-Mar-95); S8 (5-Apr-95)
2. A total of 8 samples were collected in the sampling period.

Table C.2 Enumeration (cells/liter) of plankton samples by phylum, family and species collected in Samut Sakhon province at Station 3: Canal Promdan from 7 December 1994 to 5 April 1995

Phylum	Family	Species	Number (cells/L)r	
PHYTOPLANKTON				
Cyanophyta (Blue green algae)	Oscillatoriaceae	Oscillatoria	500(S1); 125(S3); 1,680(S7)	
Chlorophyta (Green algae)				
Bacillariophyta (Diatoms)	Bacteriastraceae	Bacteriastrum	125 (S2)	
	Biddulphiaceae	Biddulphia	100(S5); 125(S6); 480(S7); 300(S8)	
	Coscinodiscaceae	Coscinodiscus	1,125(S1); 375(S3); 875(S4); 2,000(S5); 250(S6); 7,080(S7); 4,100(S8)	
			Thalassiosira	875(S6); 240(S7); 100(S8)
			Lauderia	100(S8)
	Naviculaceae	Navicula	120(S7); 700(S8)	
		Ampiphora	125(S3);	
	Pleurochloridaceae	Pleurosigma	125(S1); 375(S3); 125(S4); 1,300(S5); 500(S6); 960(S7); 1,100 (S8)	
			Nitzschiaceae	Nitzschia
	Rhizosoleniaceae	Rhizosolenia	125(S3); 375(S6); 120(S7)	
Skeletonemaceae	Skeletonema	1,875 (S1); 250(S6); 200(S8)		
Surirellaceae	Surirella	240(S7)		
Pyrrophyta (Dinoflagellata)	Peridiniidae	Peridinium	250(S2)	
		Noctiluca	375(S2); 625(S3); 2,250(S4)	
		Ceratium	125(S2); 125(S3)	
		Dinophysis	125 (S2)	
Euglenophyta				
ZOOPLANKTON				
Protozoa	Tintinnididae	Favella	125(S4)	
		Tintinnopsis	250(S2); 375(S3); 700(S5); 375(S6); 1,320(S7); 1,300(S8)	
		Tintinnus	250(S4)	
Coelenterata				
Arthropoda	-	Copepod	375 (S2); 375(S3); 375(S4); 125(S6); 120(S7)	

Notes:

1. S1 (7-Dec-94); S2 (12-Jan-95); S3 (26-Jan-95); S4 (9-Feb-95); S5 (23-Feb-95); S6 (9-Mar-95); S7 (23-Mar-95); S8 (5-Apr-95)
2. A total of 8 samples were collected in the sampling period.

Table C.3 Enumeration (cells/liter) of plankton samples by phylum, family and species collected in Samut Sakhon province at Station 5: Mouth of the Thachin river from 7 December 1994 to 5 April 1995

Phylum	Family	Species	Number (cells/L)	
PHYTOPLANKTON				
Cyanophyta (Blue green algae)	Oscillatoriaceae	Oscillatoria	200(S6)	
Chlorophyta (Green algae)				
Bacillariophyta (Diatoms)	Bacteriastraceae	Bacteriastrum	125(S4)	
	Biddulphiaceae	Biddulphia	100(S5); 200(S6); 125(S7); 120(S8)	
	Chaetoceraeae	Chaetoceros	100(S5)	
	Coccinodiscaceae	Coccinodiscus	375(S3); 200(S5); 100(S6); 500(S7); 840(S8)	
			Thalassiothrix	125(S7)
			Asterianella	120(S8)
	Naviculaceae	Navicula	300(S6); 840(S8)	
	Pleurochloridaceae	Amphora	50(S5)	
		Pleurosigma	250(S4); 250(S5); 500(S6); 500(S7); 120(S8)	
	Nitzschiaceae	Nitzschia	1,625(S3); 125(S4); 250(S5); 400(S6); 1,125(S7); 2,040(S8)	
Rhizosoleniaceae	Rhizosolenia	145(S2); 100(S5); 125(S7)		
Skeletonemaceae	Skeletonema	145(S2); 125(S3); 250(S4); 48,800(S6); 1,125(S7); 10,200(S8)		
Pyrrophyta (Dinoflagellata)	Peridiniidae	Peridinium	125(S3)	
		Noctiluca	250(S4)	
		Ceratium	125(S3); 100(S6); 125(S7)	
		Dinophysis	100(S5)	
Euglenophyta				
ZOOPLANKTON				
Protozoa				
	Tintinnididae	Tintinnopsis	8,250(S3); 1,250(S4); 250(S5); 1,100(S6); 1,000(S7); 3,120(S8)	
Coelenterata	-			
Arthropoda	-	Copepod	145(S2); 750(S3); 250(S4); 200(S5); 900(S6); 1500(S7); 840(S8)	
		Rotifera	50(S5)	

Notes:

- S1 (7-Dec-94); S2 (12-Jan-95); S3 (26-Jan-95); S4 (9-Feb-95); S5 (23-Feb-95); S6 (9-Mar-95); S7 (23-Mar-95); S8 (5-Apr-95)
- A total of 8 samples were collected in the sampling period.

Table C.4 Summary of plankton species and enumeration's (cells/L) for Station 1: Pittthayalongkorn Canal from 07 December 1994 to 05 April 1995 in the province of Samut Sakhon, Thailand

December 7th, 1994	Count (cells/L)
Rhizosolenia	2,250
Eucampia	3,480
Pleurosigma	3,000
Lauderia	2,880
Chaetoceros	3,480
Nocticula	600
Copepods	1,440
Nitzschia	6,000
Bacteriastrum	120
Melosira	120
Navicula	120
January 12, 1995	Count (cells/L)
Copepods	95
Nitzschia	190
Cyclotella	95
Tintinnopsis	190
January 26, 1995	Count (cells/L)
Nitzschia	4,950
Coscinooliscus	1,050
Biddulphia	975
Tintinnopsis	1,800
Surirella	150
Pleurosigma	975
Chaetoceros	225
Copepod	300
Bacteriastrum	75
Oscillatoria	75
Veligex	75
February 9th, 1995	Count (cells/L)
Nitzschia	1,500
Peridinium	125
Chaetoceros	6,375
Tintinnopsis	375
Biddulphia	250
Coscinodiscus	375
Pleurosigma	625
Noctiluca	500
Ceratium	125
Copepod	625
Dinophysis	125
February 23rd, 1995	Count (cells/L)
Skeletonema	16,800
Pleurosigma	9,200
Copepod	400
Nitzschia	8,400
Tintinnopsis	1,150
Biddulphia	1,000
Amphora	650
Tintinnus	50
Coscinodiscus	50
Veliger	50

Table C.4 (Continued)

March 9th, 1995	Count (cells/L)
Skeletonema	500
Tintinnopsis	4,100
Pleurosigma	3,200
Nitzschia	5,600
Ampiphora	200
Biddulphia	2,200
Coscinodiscus	1,300
Chaetoceros	300
Rhizosolenia	100
Bacteriastrium	100
Copepod	400
Surirella	100
March 23rd, 1995	Count (cells/L)
Skeletonema	2,125
Coscinodiscus	375
Biddulphia	375
Nitzschia	1,500
Pleurosigma	750
Tintinnopsis	375
April 5th, 1995	Count (cells/L)
Pleurosigma	750
Nitzschia	1,625
Biddulphia	500
Skelitonema	375
Coscinodiscus	625
Navicula	250
Noctiluca	125

Table C.5 Summary of plankton species found and enumeration's (cells/L) for Station 3: Canal Promdan from 7th December 1994 to 5th April 1995 in the province of Samut Sakhon, Thailand

December 7, 1994	Count (cells/L)
Nitzschia	2,000
Skeletonema	1,875
Coscinooliscus	1,125
Oscillatoria	500
Cambella	125
Pleurosigma	125
January 12, 1995	Count (cells/L)
Tintinnopsis	250
Nocticula	375
Peridinium	250
Bacteriastrum	125
Copepods	375
Ceratium	125
Dinophysis	125
January, 26, 1995	Count (cells/L)
Nitzschia	1,875
Nocticula	625
Rhizosolenia	125
Pleurosigma	375
Coscinodiscus	375
Ampiphora	125
Tintinnopsis	375
Ceratium	125
Oscillatoria	125
Copepod	375
Veligex	125
February 9th	Count (cells/L)
Coscinodiscus	875
Tintinnus	250
Favella	125
Noctiluca	2,250
Pleurosigma	125
Copepod	375
Nitzschia	500
February 23rd, 1995	Count (cells/L)
Pleurosigma	1,300
Coscinodiscus	2,000
Nitzschia	2,700
Tintinnopsis	700
Biddulphia	100
March 9th, 1995	Count (cells/L)
Nitzschia	1,375
Skeletonema	250
Thalassiosira	875
Pleurosigma	500
Biddulphia	125
Coscinodiscus	250
Copepod	125
Tintinnopsis	375
Rhizosolenia	375

Table C.5 (Continued)

March 23rd, 1995	Count (cells/L)
Nitzschia	32,640
Coscinodiscus	7,080
Biddulphia	480
Tintinnopsis	1,320
Copepod	120
Pleurosigma	960
Oscillatoria	1,680
Thalassiosira	240
Navicula	120
Surirella	240
Rhizosolenia	120
April 5th, 1995	Count (cells/L)
Lauderia	100
Skelitonema	200
Nitzschia	20,800
Tintinnopsis	1,300
Pleurosigma	1,100
Coscinodiscus	4,100
Biddulphia	300
Navicula	700
Thalassiosira	100

Table C.6 Summary of plankton species found and enumeration's (cells/L) collected from Station 5: Mouth of the Thachin river from 7th December 1994 to 5th April 1995 in the province of Samut Sakhon, Thailand

January 12, 1995	Count (cells/L)
Skeletonema	145
Rhizosolenia	145
Copepod	145
January 26, 1995	Count (cells/L)
Tintinnopsis	8,250
Copepod	750
Peridinium	125
Ceratium	125
Nitzschia	1,625
Coscinodiscus	375
Veligex	250
Skeletonema	125
February 9th, 1995	Count (cells/L)
Noctiluca	250
Skeletonema	250
Pleurosigma	250
Tintinnopsis	1,250
Bacteriastrum	125
Nitzschia	125
Copepod	250
February 23rd, 1995	Count (cells/L)
Nitzschia	250
Rhizosolenia	100
Coscinodiscus	200
Pleurosigma	250
Copepods	200
Tintinnopsis	250
Rotifer	50
Chaetoceros	100
Biddulphia	100
Dinophysis	100
Amphora	50
March 9th, 1995	Count (cells/L)
Copepod	900
Tintinnopsis	1,100
Skeletonema	48,800
Ceratium	100
Navicula	300
Coscinodiscus	100
Nitzschia	400
Pleurosigma	500
Biddulphia	200
Oscillatoria	200

Table C.6 (Continued)

March 23rd, 1995	Count (cells/L)
Tintinnopsis	1,000
Coscinodiscus	500
Skelitonema	1,125
Nitzschia	1,125
Copepod	1,500
Thalassiothrix	125
Rhizosolenia	125
Biddulphia	125
Ceratium	125
Pleurosigma	500
April 5th, 1995	Count (cells/L)
Skelitonema	10,200
Nitzschia	2,040
Tintinnopsis	3,120
Pleurosigma	120
Coscinodiscus	840
Biddulphia	120
Copepod	840
Navicula	840
Asterianella	120

Table C.7 Alphabetical listing of all plankton species found at Station's 1, 3 and 5 from 07 December 1994 to 05 April 1995 in the province of Samut Sakhon, Thailand

1	Amphora
2	Ampiphora
3	Asterionella
4	Bacteriastrium
5	Biddulphia
6	Cambella
7	Ceratium
8	Chaetoceros
9	Copepod
10	Coscinodiscus
11	Cyclotella
12	Dinophysis
13	Eucampia
14	Favella
15	Lauderia
16	Melosira
17	Nitzschia
18	Nocticula
19	Navicula
20	Oscillatoria
21	Peridinium
22	Pleurosigma
23	Rhizosolenia
24	Rotifer
25	Skeletonema
26	Surirella
27	Thalassiosira
28	Thalassiothrix
29	Tintinnopsis
30	Tintinnus
31	Veligex/Veliger

Appendix D: Tables supporting figures

Table D.1 Area of designated land use type and area (ha) in the province of Samut Sakhon in 1992 (Popan, 1994).

Land use type	Area (ha) by Sub-district (Amphoe)			Total
	Muang	Krathum Baen	Ban Phaeo	
Urban	3,816	1,645	1,398	6,859
Urban or community	3,149	1,085	483	4,717
Home/fruit tree area	667	560	915	2,142
Agriculture	5,040	6,304	22,253	33,597
Fruit tree crop	2,743	1,699	11,637	16,079
Vegetable crop	638	1,404	4,749	6,791
Rice paddy field	1,659	3,201	5,867	10,727
Fish and shrimp pond	11,126	838	259	12,223
Salt pan	1,028	-	-	1,028
Swamp and idle land	25,066	4,413	-	29,479
Mangrove	1,936	-	-	1,936
Total area	48,012	13,200	23,910	85,122
Number of factories	593	667	31	1,291

Table D.2 Number and area of shrimp farms in Thailand from 1976 to 1991 (NACA, 1994) and for 1994 (Anon., 1995b)

Year	Number of shrimp farms	Total farm area (ha)
1976	1,544	12,296
1977	1,437	12,411
1987	3,045	24,169
1979	3,378	24,676
1980	3,572	26,036
1981	3,657	27,459
1982	3,943	30,792
1983	4,327	35,672
1984	4,519	36,792
1985	4,939	40,769
1986	5,534	45,368
1978	5,899	52,149
1988	10,246	54,775
1989	12,545	71,166
1990	15,072	64,606
1991	18,998	76,348
1994	20,000	80,000

Table D.3 World shrimp aquaculture production (MT) from 1991 to 1994 (Anon., 1994a and Anon., 1995)

Country	1991	1992	1993	1994	Percent change	
					93/92	94/93
Thailand	153,000	163,000	209,000	229,000	+28	+10
Indonesia	140,000	130,000	100,000	120,000	-20	+20
Ecuador	100,000	95,000	76,000	93,500	-23	+23
India	35,000	45,000	55,000	75,000	+22	+36
China	145,000	140,000	30,000	55,000	-79	+83
Vietnam	30,000	35,000	40,000	47,500	+14	+19
Bangladesh	25,000	25,000	30,000	33,500	+20	+12
Philippines	30,000	25,000	25,000	32,500	-	+30
Taiwan	30,000	25,000	20,000	27,500	-20	+36
Other	45,000	46,000	54,000	-	+17.1	-
Total	733,100	729,000	644,000	713,500	-12	+11

Table D.4 Total marine shrimp production in Thailand (MT) from 1972 to 1991 and the quantities and percentage produced by aquaculture and sea capture for each year (NACA, 1994)

Year	Production of shrimp			
	Total (MT)	Culture (MT)	Capture (MT)	% cultured
1972	67,878	991	66,887	1.5
1973	79,160	1,635	77,525	2.0
1974	81,868	1,775	80,093	2.1
1975	87,039	2,538	84,501	2.9
1976	88,677	2,538	86,139	2.8
1977	118,953	1,590	117,363	1.3
1978	127,404	6,395	121,009	5.0
1979	116,456	7,064	109,392	6.1
1980	118,340	8,063	110,278	6.8
1981	133,435	10,728	122,707	8.0
1982	166,614	10,091	156,523	6.0
1983	139,134	11,550	127,584	8.3
1984	117,401	13,007	104,394	11.1
1985	107,472	15,841	91,631	14.8
1986	120,413	17,886	102,527	14.8
1987	129,777	23,566	106,211	18.1
1988	141,503	55,633	85,870	39.3
1989	178,699	93,495	85,204	52.3
1990	200,724	118,227	82,497	58.9
1991	242,070	162,070	80,000	67.0

Appendix E: Data from field investigation in Samut Sakhon

	07-Dec-94	12-Jan-95	26-Jan-95	09-Feb-95	23-Feb-95	09-Mar-95	23-Mar-95	05-Apr-95
n=8	S1	S2	S3	S4	S5	S6	S7	S8
Secchi Disk Depth (cm)	50	35	15	20	20	20	15	25
Depth (m)	4	3.75	4.2	4.2	3.8	3.8	3.7	3
Air Temperature (°C)	32.5	31	30	30	29	31	30	28
Water Temperature (°C)	28.5	26.5	29	26	30	30	29.5	30
Salinity surface (ppt)	32	20	30	31	27	27	26	30
pH	8.1	8.3	8.2	8	8.4	8	8.3	7.3
DO	3.5	4.2	4.3	4.5	4.7	4.6	3.6	3
Nitrate (mg/L)	0.4064	0.2397	0.3488	0.1797	0.0474	0.112	0.0935	0.0909
Nitrite (mg/L)	0.0451	0.1061	0.1465	0.0778	0.0206	0.0449	0.071	0.0237
Ammonia (mg/L)	0.1623	1.0763	0.1422	0.1524	0.0063	0.1962	0.0207	0.2917
Orthophosphate (mg/L)	0.1486	0.2692	0.2202	0.082	0.097	0.246	0.2339	0.243
TSS (g/L)	0.45	0.266	0.534	0.494	0.51	0.556	0.432	0.494
Chlorophyll a (mg/L)	1.19	7.14	14.28	8.7266	45.22	11.305	45.22	2.38

	07-Dec-94	12-Jan-95	26-Jan-95	09-Feb-95	23-Feb-95	09-Mar-95	23-Mar-95	05-Apr-95
n=8	S1-pond 1	S2-pond 2	S3-pond 2	S4-pond 2	S5-pond 2	S6-pond 2	S7-pond 2	S8-pond 1
Secchi Disk Depth (cm)	25	15	15	15	15	15	18	10
Depth (m)	0.67	1.3	1.3	1.5	1.35	1.5	1.5	1.4
Air Temperature (°C)	32	32	32	30	30	31.5	30	32.5
Water Temperature (°C)	29	27	30	28	31	32	32	32
Salinity surface (ppt)	6	7	10	9	10	10	15	15
pH	8.7	8.7	8.7	8.4	8.5	8	8.4	7.9
DO (mg/L)	10.6	6.7	6.6	8.3	8.3	6.2	6.4	7.3
Nitrate (mg/L)	0.117	0.1983	0.1128	0.0812	0.1894	0.4035	0.664	0.0175
Nitrite (mg/L)	0.0051	0.1061	0.0364	0.0152	0.2785	0.5431	0.8437	0.0019
Ammonia (mg/L)	0.0938	0.5858	0.2149	0.1229	0.1107	0.1909	0.664	0.1992
Orthophosphate (mg/L)	0.4153	0.111	0.7582	0.0331	0.2486	0.384	0.5615	0.4567
TSS (g/L)	0.14	0.106	0.252	0.276	0.388	0.438	0.38	0.404
Chlorophyll a (mg/l)	19.63	46.41	289.17	95.2	189.21	10.71	114.24	145.18

Appendix E: Data from field investigation in Samut Sakhon

Table E.3 Summary of field data collected at Sample Station Three in Samut Sakhon, Thailand from 07-Dec-94 until 05-Apr-95.								
	07-Dec-94	12-Jan-95	26-Jan-95	09-Feb-95	23-Feb-95	09-Mar-95	23-Mar-95	05-Apr-95
n=8	S1	S2	S3	S4	S5	S6	S7	S8
Secchi Disk Depth (cm)	30	90	45	20	5	5	5	5
Depth (m)	1.4	1.6	1.6	0.9	0.85	0.9	0.9	0.7
Air temperature (°C)	32.5	32	32	31	32	33	32	29
Water temperature (°C)	31	27	29	28	31	32	33	33
Salinity surface (ppt)	30	28	24	29	24	25	26	24
pH	7.8	8.3	8	8	8.2	8	8.2	7.3
DO (mg/L)	6.8	7.7	5.3	5.5	5.2	5.9	5.5	4.4
Nitrate (mg/L)	0.3951	0.1265	0.2489	0.1933	0.1153	0.1196	0.3045	0.0591
Nitrite (mg/L)	0.0564	0.0113	0.0349	0.0101	0.435	0.039	0.0335	0.011
Ammonia (mg/L)	0.21	0.2109	0.1432	0.1882	0.0289	0.0634	0.0983	0.1572
Orthophosphate	0.1417	0.111	0.153	0.0242	0.1775	0.1885	0.116	0.1928
TSS (G/L)	0.51	0.258	0.664	0.452	0.77	0.538	1.638	0.482
Chlorophyll a (mg/L)	1.19	5.95	19.635	12.495	63.07	7.14	18.246	23.8
Table E.4 Summary of field data collected at Sample Station Four in Samut Sakhon, Thailand from 07-Dec-94 until 05-Apr-95.								
	07-Dec-94	09-Feb-95	23-Feb-95	09-Mar-95	23-Mar-95	05-Apr-95		
n=6	S1	S4	S5	S6	S7	S8		
Secchi Disk Depth (cm)	45	30	25	25	20	20		
Depth (m)	0.9	1	0.65	0.9	1.1	0.9		
Air Temperature (°C)	32.5	31	32	32	31	30.5		
Water Temperature (°C)	32	30	33	33	36	34		
Salinity surface (ppt)	29	24	30	22	31	30		
pH	8.2	8.2	8.6	8.2	8.6	7.7		
DO (mg/L)	9.4	5.7	9.6	8.9	8	7		
Nitrate (mg/L)	0.0883	0.0697	0.0452	0.0947	0.1149	0.0215		
Nitrite (mg/L)	0.051	0.0364	0.0069	0.0201	0.0128	0.0041		
Ammonia (mg/L)	0.0433	0.0443	0.0051	0.0221	0.1101	0.1178		
Orthophosphate (mg/L)	0.1603	0.0084	0.2045	0.157	0.335	0.3295		
TSS (g/L)	0.45	0.486	0.06	0.468	0.47	0.534		
Chlorophyll a (mg/L)	1.19	21.42	28.56	5.355	35.7	33.32		
Note: n=6; No sample collection at Sample Station 4 on 12-Jan-95 and 26-Jan-95; pond was empty between crops.								

Table E.5 Summary of field data collected at Sample Station Five in Samut Sakhon, Thailand from 12-Jan-95 until 05-Apr-95.							
	12-Jan-95	26-Jan-95	09-Feb-95	23-Feb-95	09-Mar-95	23-Mar-95	05-Apr-95
n=8	S1	S2	S3	S4	S5	S6	S7
Secchi Disk Depth (cm)	80	60	60	35	35	20	30
Depth (m)	3.5	3.8	3.4	3	3	2.7	2
Air Temperature (°C)	30	30	31	29	30	30	30
Water Temperature (°C)	28	29	27	30	30.5	31.5	32
Salinity surface (ppt)	17	26	19	25	15	25	20
pH Surface	7.8	8	7.6	8	7.9	8	7
DO (mg/L)	3.4	3.9	2.6	5.3	5.3	3.9	1.9
Nitrate (mg/L)	0.22	0.257	0.2905	0.1727	0.2229	0.1352	0.3079
Nitrite (mg/L)	0.1376	0.1646	0.1771	0.1263	0.2622	0.1576	0.2875
Ammonia (mg/L)	3.4509	0.1476	0.4824	0.0215	0.0621	0.1542	0.4461
Orthophosphate (mg/L)	0.6861	0.2718	0.1768	0.2491	0.4382	0.3254	0.5223
TSS (g/L)	0.12	0.594	0.282	0.454	0.28	0.358	0.294
Chlorophyll a (mg/L)	5.95	5.355	17.255	17.05	3.57	3.173	28.56

Appendix F: Results of Data Analysis

Table F.1 Results of analysis of the physical and chemical parameters collected from Sample Station One							
n=8	SDD (cm)	Depth (m)	AT(°C)	WT(°C)	Salinity (ppt)	pH	DO (mg/L)
Mean	25	3.8	30.2	28.7	28	8.1	4.1
Standard Error	4.2	0.13	0.5	0.6	1.4	0.1	0.2
Standard Deviation	12	0.38	1.4	1.6	3.8	0.3	0.6
Sample Variance	142.9	0.14	1.9	2.6	14.7	0.1	0.4
Range	35	1.2	4.5	4	12	1.1	1.7
Minimum	15	3	28	26	20	7.3	3
Maximum	50	4.2	32.5	30	32	8.4	4.7
Table F.2 Results of analysis of the inorganic contaminant parameters collected from Sample Station One							
n=8	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	Orthophosphate (mg/L)	TSS (g/L)	Chl a (mg/L)	
Mean	0.1898	0.067	0.256	0.1925	0.467	16.93	
Standard Error	0.0463	0.0152	0.1216	0.0257	0.0321	6.36	
Standard Deviation	0.131	0.0431	0.344	0.0727	0.0907	17.98	
Sample Variance	0.0172	0.0019	0.1183	0.0053	0.0082	323.13	
Range	0.359	0.1259	1.07	0.1872	0.29	44.03	
Minimum	0.0474	0.0206	0.0063	0.082	0.266	1.19	
Maximum	0.4064	0.1465	1.0763	0.2692	0.556	45.22	
Table F.3 Results of analysis of the physical and chemical parameters collected from Sample Station Two							
n=8	SDD (cm)	Depth (m)	AT (°C)	WT (°C)	Salinity (ppt)	pH	DO (mg/L)
Mean	16	1.32	31.3	30.1	10.3	8.4	7.6
Standard Error	1.5	0.1	0.4	0.7	1.2	0.1	0.5
Standard Deviation	4.2	0.27	1.1	2	3.3	0.3	1.5
Sample Variance	18	0.08	1.11	3.8	10.8	0.1	2.2
Range	15	0.83	2.5	5	9	0.8	4.4
Minimum	10	0.67	30	27	6	7.9	6.2
Maximum	25	1.5	32.5	32	15	8.7	10.6
Table F.4 Results of analysis of the inorganic contaminant parameters collected from Sample Station Two							
n=8	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	Orthophosphate (mg/L)	TSS (g/L)	Chl a (mg/l)	
Mean	0.223	0.2288	0.2728	0.3711	0.298	113.72	
Standard Error	0.0749	0.1101	0.0787	0.0837	0.0443	33.22	
Standard Deviation	0.212	0.3114	0.2227	0.2368	0.1254	93.97	
Sample Variance	0.0449	0.0969	0.0496	0.0561	0.0157	8829.87	
Range	0.6465	0.8418	0.5702	0.7251	0.332	278.46	
Minimum	0.0175	0.0019	0.0938	0.0331	0.106	10.71	
Maximum	0.664	0.8437	0.664	0.7582	0.438	289.17	

Appendix F: Results of Data Analysis

Table F.5 Results of analysis of the physical and chemical parameters collected from Sample Station Three							
n=8	SDD (cm)	Depth (m)	AT(°C)	WT(°C)	Salinity (ppt)	pH	DO (mg/L)
Mean	25.6	1.11	31.7	30.5	26.3	8	5.8
Standard Error	10.6	0.13	0.4	0.8	0.9	0.1	0.4
Standard Deviator	29.9	0.36	1.2	2.3	2.4	0.3	1
Sample Variance	896	0.13	1.5	5.1	5.9	0.1	1.1
Range	85	0.9	4	6	6	1	3.3
Minimum	5	0.7	29	27	24	7.3	4.4
Maximum	90	1.6	33	33	30	8.3	7.7
Table F.6 Results of analysis of the inorganic contaminant parameters collected from Sample Station Three.							
n=8	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	Orthophosphate	TSS (g/L)	Chl A (mg/L)	
Mean	0.1953	0.0789	0.1375	0.1381	0.664	18.9	
Standard Error	0.0401	0.0512	0.0241	0.0196	0.1489	6.9	
Standard Deviator	0.1135	0.1448	0.0681	0.0554	0.4213	19.4	
Sample Variance	0.0129	0.021	0.0046	0.0031	0.1775	376.66	
Range	0.336	0.4249	0.182	0.1686	1.38	61.88	
Minimum	0.0591	0.0101	0.0289	0.0242	0.258	1.19	
Maximum	0.3951	0.435	0.2109	0.1928	1.638	63.07	
Table F.7 Results of analysis of the physical and chemical parameters collected from Sample Station Four.							
n=6	SDD (cm)	Depth (m)	AT(°C)	WT(°C)	Salinity (ppt)	pH	DO (mg/L)
Mean	27.5	0.91	31.5	33	27.7	8.3	8.1
Standard Error	3.8	0.06	0.3	0.8	1.5	0.1	0.6
Standard Deviator	9.4	0.15	0.8	2	3.7	0.3	1.5
Sample Variance	87.5	0.02	0.6	4	13.9	0.1	2.3
Range	25	0.45	2	6	9	0.9	3.9
Minimum	20	0.65	30.5	30	22	7.7	5.7
Maximum	45	1.1	32.5	36	31	8.6	9.6
Table F.8 Results of analysis of the inorganic contaminant parameters collected from Sample Station Four.							
n=6	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	Orthophosphate (mg/L)	TSS (g/L)	Chl a (mg/L)	
Mean	0.0724	0.0219	0.0571	0.1991	0.4113	20.92	
Standard Error	0.014	0.0075	0.019	0.05	0.0712	5.95	
Standard Deviator	0.0343	0.0184	0.0464	0.1226	0.1745	14.58	
Sample Variance	0.0012	0.0003	0.0022	0.015	0.0304	212.47	
Range	0.0934	0.0469	0.1127	0.3266	0.474	34.51	
Minimum	0.0215	0.0041	0.0051	0.0084	0.06	1.19	
Maximum	0.1149	0.051	0.1178	0.335	0.534	35.7	

Table F.9 Results of analysis of the physical and chemical parameters collected from Sample Station Five.							
n=7	SDD (cm)	Depth (m)	AT(° C)	WT(°C)	Salinity (ppt)	pH	DO (mg/L)
Mean	45.7	3.06	30	29.7	21	7.8	3.8
Standard Error	8	0.22	0.2	0.7	1.6	0.1	0.5
Standard Deviation	21.3	0.59	0.6	1.8	4.4	0.4	1.3
Sample Variance	453.6	0.35	0.3	3.3	19	0.1	1.6
Range	60	1.8	2	5	11	1	3.4
Minimum	20	2	29	27	15	7	1.9
Maximum	80	3.8	31	32	26	8	5.3
Table F.10 Results of analysis of the inorganic contaminant parameters collected from Sample Station Five.							
n=7	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	Orthophosphate (mg/L)	TSS (g/L)	Chl a (mg/L)	
Mean	0.2295	0.1876	0.6807	0.3814	0.3403	11.56	
Standard Error	0.0233	0.0236	0.4667	0.0673	0.0568	3.64	
Standard Deviation	0.0617	0.0624	1.2347	0.1782	0.1502	9.62	
Sample Variance	0.0038	0.0039	1.5245	0.0317	0.0226	92.62	
Range	0.1727	0.1612	3.4294	0.5093	0.474	25.39	
Minimum	0.1352	0.1263	0.0215	0.1768	0.12	3.17	
Maximum	0.3079	0.2875	3.4509	0.6861	0.594	28.56	

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