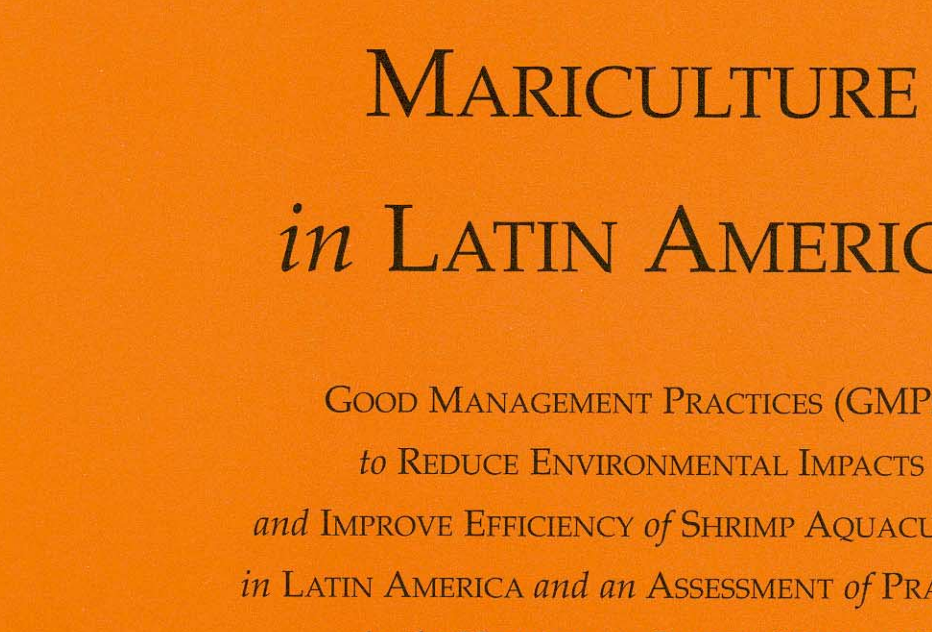
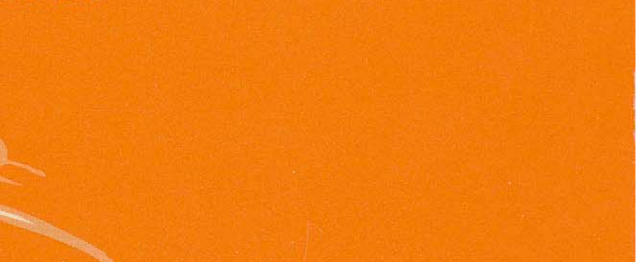
IMPROVING SHRIMP MARICULTURE *in* LATIN AMERICA

GOOD MANAGEMENT PRACTICES (GMPs)
to REDUCE ENVIRONMENTAL IMPACTS
and IMPROVE EFFICIENCY *of* SHRIMP AQUACULTURE
in LATIN AMERICA *and an* ASSESSMENT *of* PRACTICES
in the HONDURAN SHRIMP INDUSTRY





COASTAL RESOURCES CENTER
University of Rhode Island

SHRIMP MARICULTURE IN LATIN AMERICA
SHRIMP MARICULTURE IN LATIN AMERICA SHRIMP MARICULTURE IN LATIN AMERICA

IMPROVING SHRIMP MARICULTURE in LATIN AMERICA

GOOD MANAGEMENT PRACTICES (GMPS) to REDUCE ENVIRONMENTAL IMPACTS and IMPROVE EFFICIENCY of SHRIMP AQUACULTURE in LATIN AMERICA and an ASSESSMENT of PRACTICES in the HONDURAN SHRIMP INDUSTRY

Claude E. Boyd
P.O. Box 3074
Auburn, Alabama 36831
U.S.A.

Maria C. Haws
Coastal Resources Center
University of Rhode Island
Narragansett, Rhode Island 02882
U.S.A.

Bartholomew W. Green
Department of Fisheries and Allied Aquaculture
Auburn University, Alabama 36849-5419
U.S.A.

Table of Contents

ABSTRACT

Practices that can be used to improve the efficiency and reduce the negative environmental impacts of shrimp farming are presented. The practices are called good management practices (GMPs) instead of best management practices (BMPs), because the best ways of reducing environmental impacts in shrimp farming are still evolving. The practices were developed specifically for shrimp culture in Latin American countries and represent an effort to move from the level of general Codes of Practices accepted at international levels to good management practices applicable to specific regional industries. The recommended GMPs were developed using a participatory process and with the assistance of the National Honduran Aquaculture Association (ANDAH). Many of the practices are applicable to shrimp farming anywhere in the world and to most other types of pond aquaculture. Further modifications and refinements are anticipated for these GMPs as a result of continued collaboration with shrimp producers and aquacultural scientists. A field survey was conducted to evaluate the degree of adoption by Honduran shrimp producers of selected GMPs believed to be the most critical including feeding, fertilization and health management practices. Survey findings indicate that overall adoption was about 70 percent. In the process of conducting the field survey, a number of areas were detected where improvement is needed; this information can be used to guide research, training and extension priorities.

PREFACE

Practices that can be used to improve the efficiency and reduce environmental impacts of shrimp farming are presented in this report. The practices are called good management practices (GMPs) rather than best management practices (BMPs), because the best ways of reducing environmental impacts in shrimp farming are still evolving. These practices were developed specifically for shrimp culture in Honduras, although most will be applicable throughout Latin America. Development of these GMPs represents an effort to move from generic Codes of Practices prepared at the international level to detailed good management practices applicable to specific regional industries.

The GMPs presented in this document represent a consensus among scientists, Honduran industry members and environmental managers of what constitutes a good management practice that could be implemented by producers under current circumstances. A field survey was conducted to evaluate the degree of adoption by Honduran shrimp producers of selected GMPs believed to be the most critical including feeding, fertilization and health management practices. Survey findings indicate that overall adoption is about 70 percent. In the process of conducting the field survey, a number of areas were detected where improvement is needed; recommendations in these areas for research, training and extension are also presented in this report.

The success of this work on GMPs has resulted in several follow-up projects and activities in Central America and Mexico that directly build on the work and findings described here. These activities are being supported by the United States Agency for International Development (USAID), United States Department of Agriculture, and the David and Lucile Packard Foundation.

This report was prepared in collaboration with the Honduran National Aquaculture Association (ANDAH), and with funding from ANDAH and the USAID Office of Regional Sustainable Development, Bureau for Latin America and the Caribbean. The University of Rhode Island's Coastal Resources Center (CRC) provided overall leadership for the effort. CRC

is dedicated to advancing coastal management worldwide through field projects, research and learning, education and training, and networking and information sharing. Through its cooperative agreement with USAID, CRC has lead a series of applied research activities to develop methods and strategies for enhancing the environmental and economic sustainability of shrimp aquaculture. The Department of Fisheries and Allied Aquaculture, Auburn University, is dedicated to sustainable aquaculture and fisheries development and has active research programs in the US and overseas.

The authors of this report are Dr. Maria C. Haws, University of Hawaii at Hilo, and Dr. Claude E. Boyd and Dr. Bartholomew W. Green from the International Center for Aquaculture and Aquatic Environments, Department of Fisheries and Allied Aquaculture, Auburn University. A team of international experts reviewed and provided comments on the content of an earlier draft of the report. Financial support for publication of this report comes in part from Auburn University.

1.0

Rationale for Developing Good Management Practices

Like other forms of aquaculture, shrimp aquaculture has a bright future. Shrimp aquaculture has grown rapidly from accounting for less than 10 percent of total world shrimp production in 1984, to nearly 25 percent since 1990 (FAO 1996). Demand for fisheries products continues to rise while wild stocks decrease, thus creating a growing niche for aquaculture production. Shrimp production has become an important new export industry in Latin America and the Caribbean with significant effects on natural resource use, local and regional economies and surrounding communities. As the shrimp aquaculture industry continues to grow and place pressure on coastal resources, sustainability can best be achieved by proactively seeking viable means to minimize potential impacts, maintain the natural resource base, and maximize benefits.

Without a sound scientific basis, rational regulation for aquaculture cannot be developed. These regulations must also set appropriate environmental protection standards. Adequate policy and a functional regulatory framework are also necessary preconditions for sustainable production. In many countries, environmental management guidelines and enabling legislation are lacking. In some cases, existing guidelines and legislation may be in place, but they may not be entirely applicable to specific forms of aquaculture. Even where such legislation is in place, financial and institutional capacity to effectively implement environmental management initiatives may not be available. Even a well-conceived and implemented regulatory approach can be inadequate to the task of ensuring sustainable aquaculture practice.

Shrimp aquaculture takes many forms, and each type may be practiced in a number of ways. Decisions that affect the environment and productivity are made on a daily basis by individuals with a wide range of technical capacity. The diversity and complexity of this activity makes it difficult to develop a regulatory approach that is sufficiently comprehensive, yet flexible enough, that producers can adapt to changing circumstances. Whether a regulatory approach is effective or not, producers who are responsible for the daily management of aquaculture operations play the most direct role in formulating and implementing the best available practices. These limitations make it likely that promulgating a rational, practicable set of regulations to govern shrimp farm development and practice in the immediate future will be difficult in many countries, and oversight will be inadequate. A more effective and rapid approach is the formulation, testing and use of "good practices" by shrimp producers, researchers and environmental managers. This approach must be able to lay the groundwork for development of future environmental management initiatives with a sound scientific basis. Self-regulation founded in sound technical capability can make shrimp aquaculture, or any type of aquaculture, more environmentally responsible. This will occur without governmental regulation if producers are given the incentives and are made aware of these.

Additionally, the shrimp industry cannot be considered in isolation. Other industries impact the environment and may affect shrimp culture operations that depend upon maintenance of environmental quality for successful operation. Thus, while development of good management practices (GMP) for shrimp culture is a positive step forward, other industries occupying the same ecosystem also require similar self-regulation if environmental protection is to be effective.

Characteristics of Good Management Practices

2.0

Practical experience and scientific research provide a sufficient basis for the development of GMPs for shrimp farming, and progress is being made on many fronts. Phillips (1995), Boyd and Tucker (1998), and Boyd (1997a) discuss general methods for reducing environmental impacts of pond aquaculture. Brunson (1997) prepared a code of practice for channel catfish farming that is applicable to some aspects of shrimp farming. Boyd and Queiroz (1997) discuss aquaculture pond effluent management. Tookwinas (1996) considers ways of lessening the environmental impact of intensive shrimp farms in Thailand, and the Association of Southeast Asian Nations (1997) has prepared a manual to coordinate good shrimp farm management practices. Donovan (1997) prepared an "Environmental Code of Practice" for Australian shrimp farmers. Dixon (1997) presented an environmental code of practice for the Belize shrimp farming industry. Boyd et al. (1998a) discussed the variables that should be considered in developing more "environmentally-friendly" pond aquaculture. Boyd and Massaut (1998) discuss the role of soils in site selection, construction and operation of aquaculture farms.

Several organizations have also undertaken development of voluntary codes of practice or guidelines. A new shrimp industry group, Global Aquaculture Alliance (GAA), has prepared a general code of practices for shrimp farming (Boyd 1998). The GAA plans to continually improve this code of practices as technology advances, and they encourage other groups to use the general code of practices as a basis for developing more specific codes or practices. In 1997, the Food and Agriculture Organization sponsored a meeting to elaborate on voluntary codes of practice, "Bangkok Food and Agriculture Organization (FAO) Technical Consultation on Policies for Sustainable Shrimp Culture" that outlined a number of considerations for working towards sustainability at the state level (FAO 1997). Two nongovernmental environmental organizations, the Industrial Shrimp Action Network and the Environ-mental Defense Fund, also produced versions of best management practices in 1998.

In summary, there is widespread interest in codes of practice to minimize the potential impacts of shrimp farming. The codes of practices mentioned above are generally similar in their overall objectives, although they differ in their specificity and scope. These codes attempt to define characteristics of sustainable practices and set objectives to be achieved. In general, the methods to achieve these goals are only broadly outlined. Since these codes of practice are written in the context of a global industry, the generality of the recommendations is appropriate.

The aim of this initiative is to build on the current scientific basis and pioneering environmental management efforts by identifying the best existing technical methods and strategies to achieve the objectives specified in the various codes of practice. Recognizing that the shrimp industry in the Latin America and the Caribbean region differs in important ways from other regional industries, an effort is made to select methods and strategies that are specific and appropriate to this industry.

The level of specificity for each topic covered by the GMPs will vary according to what is currently used and the available technical knowledge. For example, the pond construction guidelines are much more specific than those for feeding and fertilization for two reasons. First, pond construction is not new, and the practices are closer to optimization than practices related to providing good shrimp nutrition. Second, construction is also less likely than nutrition to be affected by complex environmental interactions. The degree of specificity definable for each topic is also an indicator of which areas in the field require more testing and refinement, or which need more flexibility. It is clear that feeding and fertilization practices can be improved through further investigation.

It should also be noted that there is a high degree of variability between shrimp farms, sources of water, ecosystems in which farms are located and season variations that will affect the nature and development of GMPs. Consideration of this variability is important in determining the specificity of GMPs.

The methods and strategies offered here have been named "good management practices" in recognition that the industry is constantly evolving and improving its technical capability. The term "best management practices," often used in environmental management, is not entirely accurate. New and better methods will become available as knowledge and practice advances. It should also be acknowledged that in some cases, better technology may exist to resolve some problems, but use of this technology may not be feasible for a variety of reasons.

The GMPs should not be viewed as quantitative, static procedures that can be permanently codified as regulation. Aside from the fact that better methods will be developed, current good management practices require a degree of flexibility and good judgement by farm managers. It is they who must react to constantly changing environmental, economic and social conditions. The GMPs are intended to guide, not arbitrarily restrict, farm managers.

The utility of GMPs rests in their voluntary nature. As voluntary practices, they can be continually tested and modified by researchers and producers.

Who Can Benefit from Good Management Practices

3.0

Shrimp producers will be the primary beneficiaries of GMPs and can use them in several ways. First, the process of developing GMPs will require that industry leaders are able to agree upon acceptable and useful practices to protect natural resources. Any industry will be heterogeneous in the ability of individual producers to identify and refine good practices, with a few innovative individuals leading the way. A region's environmental quality is subject to the pressures exerted by all users; thus, it is in the interest of progressive producers to promote good practices throughout their region. Additionally, employing good practices enhances the industry's image and demonstrates responsibility. The new producers or industries can develop their own site-specific versions of these GMPs by using the following Honduran case as a model.

There are economic incentives for producers to implement GMPs. Most GMPs will have dual outcomes by improving production efficiency and reducing potential impacts. Conceivably, producers and other interested stakeholders could use GMPs as a framework for establishing criteria for certification and product differentiation, thus gaining a marketing advantage.

Researchers and extension workers can use GMPs to guiding applied research efforts and assist in focusing technical assistance programs. GMPs for certain topics clearly need more definition. This will be achieved by continued research and development. The existence of a recognized set of GMPs provides a common ground for discussion and collaboration between the industry and technical specialists.

Resource managers can benefit from GMPs that help to identify practicable means of maintaining environmental quality. For example, GMPs related to good construction practice and siting criteria can provide a sound basis for improving land use classification and zoning. GMPs can help build awareness of the complexity of the industry, and provide a better technical understanding of the field to enable resource managers to formulate sensible policies and regulations.

4.0 METHODOLOGY USED in DEVELOPING GOOD MANAGEMENT PRACTICES

Collaborative development of GMPs

This initiative builds on previous work by individual researchers and organizations to develop voluntary codes of practice, and using these as a conceptual framework to guide elaboration of more specific and implementable guidelines. The strategy employed in this work is the identification and sizing of tangible means to move further along the spectrum from concept to practice. This effort will serve as a paradigm for developing ways for coastal managers, researchers and the industry to work together to share their knowledge and experience to promote implementation of good practices. The first step is to arrive at a mutual understanding and consensus of what these good practices and methods are, based on the best scientific and technical knowledge available.

The methodology used in this project was predicated on stakeholder consultation and collaboration. The first step was to develop a set of draft GMPs that represented the best judgement of scientific and technical specialists from academia and industry. The first version of the GMPs was prepared by Claude E. Boyd (Auburn University), who has extensive experience with shrimp aquaculture, water quality, and sediment chemistry, and who has taken the lead in preparing other voluntary codes of practice. He was assisted by coastal managers James Tobey (economist) and Maria Haws (ecologist) of the Coastal Resources Center, University of Rhode Island. Preliminary consultations were initiated with the Honduran Shrimp Producers Association (ANDAH) with assistance from Bartholomew Green [Auburn University, Pond Dynamics/ Aquaculture Cooperative Research Support Program (PD/ACRSP)], who has been active in shrimp culture research and environmental monitoring in Honduras. The first draft was intended to be a broad framework for developing GMPs based on previous work, and to provide a starting point for discussion with the producers' association.

The first draft of the GMPs was reviewed by a panel of shrimp culture specialists and resource managers, including ANDAH. At this point, the work became more narrowly focused on practices suited for the current semi-intensive industry in Honduras. ANDAH was then instrumental in contributing information and lessons learned from the Honduran experience with shrimp aquaculture. The GMPs presented here are thus a consensus of researchers, technical specialists and shrimp producers for practices which achieve the desired objectives while remaining practical and feasible to implement under current industry conditions.

The GMPs are based on the best current knowledge of industry practitioners and technical experts. However, common in many industries, actual practices lag behind generally accepted good practices for a variety of reasons. A comparison of the GMPs and actual industry practices was desirable to determine the level of adoption. Additionally, where it is found that a particular

GMP is not widely practiced, determining why it is not practiced provides useful information for developing training and extension strategies to improve the level of adoption. A better understanding of industry practices and the decisionmaking process of shrimp farm management is important as a means to "ground-truth" the GMPs. This is because some GMPs may simply prove to be unfeasible, too costly or otherwise unacceptable; consequently, specific GMPs would need to be modified if they are to be implemented.

A field survey was designed to characterize industry practices and assess the level of adoption. The field survey focuses on priority topics for the industry: health, fertilization and feeding. Industry members felt these were the critical areas that most affected production, and in these areas change was possible. Not all GMP areas are amenable to study in this fashion since collecting the required data or making observations may not be feasible or may be outside the scope of this work. For example, little information was collected on pond construction since no pond construction was in progress, and the reliability of historical data was unknown. Additionally, the field survey was conducted after Hurricane Mitch devastated the shrimp industry and the surrounding countryside in October 1998. The hurricane destroyed infrastructure and financially taxed the industry. Some questions were added to the field survey to determine if damage could have been prevented through using different construction or siting strategies, or if farm management practices had changed due to the economic difficulties the farms were experiencing.

The feeding, fertilization, and health management GMPs evaluated by the survey are listed in Appendix A. For ease of comparison with the recommended GMPs, the findings from the field survey have been inserted as text boxes at key points in this document. Quantitative results of the survey are summarized in Appendix B.

5.0 The Scope and Intent of Good Management Practices

GMPs are intended to represent a general list of practices and methods that can be adapted to yield the greatest benefits for the least cost for an individual farm. The GMPs proposed in this paper are designed to fulfill two functions: improve cost-efficiency of production and minimize off-site environmental impacts. Most GMPs have positive effects on both production efficiency and the environment, although the environmental benefit-cost ratio will vary considerably. Some GMPs may appear to address only production efficiency while others seem to only address environmental protection. In reality, the two aspects of GMPs cannot be uncoupled and must be addressed simultaneously. Cost-efficient production over the long term depends on maintaining environmental quality. Conversely, improving those practices that contribute to optimal production efficiency over the long term will generally have a positive effect on environmental impacts. Increasing feeding and fertilizing efficiency is an example because increased efficiency reduces costs and also improves effluent quality.

GMPs will span a wide spectrum of practices ranging from fundamental issues such as feeding and stocking rates, to seemly trivial construction details. However, good stewardship often involves doing many small things properly rather than making one or two major changes. Ponds are aquatic ecosystems and their management should be viewed as ecosystem management, requiring a good understanding of the inter-relatedness of practices and their effects. As with most ecosystems, a small change or many small changes made in tandem can have significant effects.

GMPs are not intended to be final and static recommendations. Technology and human capacity are continuously evolving. If GMPs are to fulfill their purpose of improving efficiency and reducing impacts, they require periodic evaluation and refinement. Part of the periodic updating of GMPs is having sufficiently good information on their benefits and costs to evaluate their effectiveness.

Socioeconomic issues are not directly addressed in this paper, although their importance is recognized. Shrimp aquaculture can both affect and be affected by socioeconomic parameters. However, adherence to the siting and operational GMPs described here will have socioeconomic benefits because environmental quality, protection of human safety and health, and economic development are key factors in determining quality of life for the residents of shrimp farming areas. Analysis of socioeconomic aspects deserves further study so site-specific guidelines for enhancing societal benefits from shrimp aquaculture can be developed and evaluated.

The proposed GMPs cover the major activities in shrimp farming: site selection, farm design and construction, and facility operation. The field survey was designed to characterize the industry and determine the level of adoption of recommended GMPs. It was limited to topic areas most critical in terms of protecting the environment and increasing economic returns. Limited time and resources imposed limitations on the range of topics that could be covered during the field survey. Areas chosen were also based on the ability to collect accurate and reliable information under existing field conditions.

6.0 Characteristics of the Honduras Shrimp Industry

The shrimp industry considered in this study is located in southern Honduras; most farms are located in the eastern region of the Gulf of Fonseca (in the vicinity of Monypenny Bay). Shrimp farming began in the early 1970s in Honduras, and since 1985, total area under cultivation increased from less than 1,000 hectares (ha) to 15,000 ha in 1999 (Figure 1). Average farm age was eight and one-third years, with the oldest farm being 26 years old and the newest farm 1 1/2 years old. In Nicaragua, development of shrimp farming took place in the 1990s. While for this study only Honduran farms were included, from an ecosystems perspective the industries in these two areas may in some ways be considered a single industry.

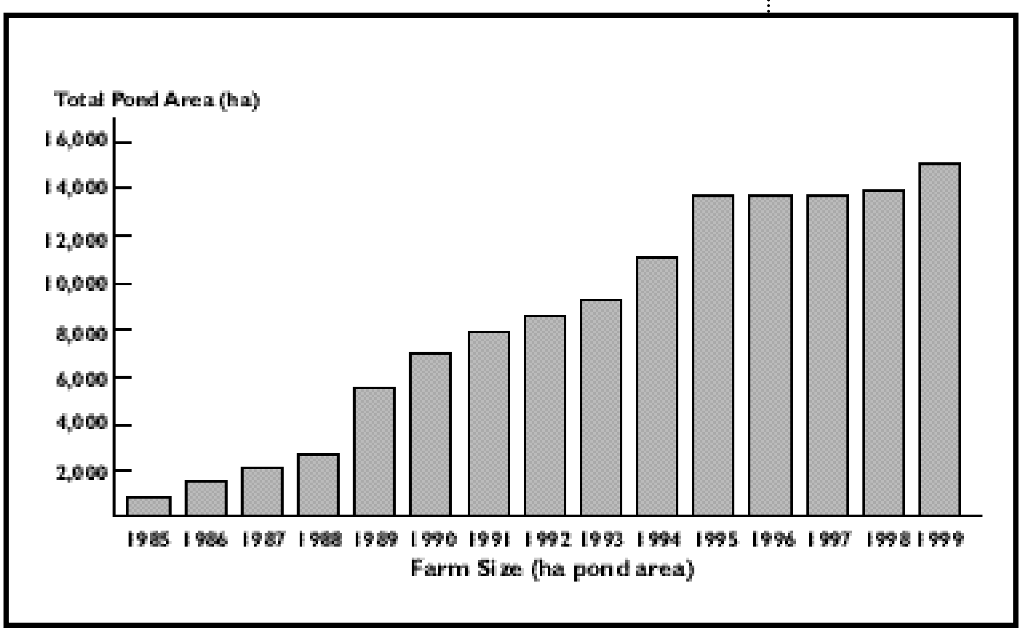


Figure 1. Total shrimp pond area (in hectares) in southern Honduras from 1985 to 1999.

Shrimp farms surveyed for the purpose of assessing the level of adoption with the GMPs ranged in size from 8 ha to 3,220 ha (the largest in the area), and averaged 392 ha per farm. The total pond area of the 29 farms visited summed 11,378 ha, representing 76 percent of total shrimp pond area in 1999. Farms had an average of 28 ponds (range: 2-146). Farms often had both production and nursery ponds, but production ponds predominated. Nursery ponds were used either to stockpile wild-caught post-larval shrimp (PL) during periods of abundance or for grow-out.

In 1999, total production of whole shrimp (primarily *Penaeus vannamei* and a small amount of *P. stylirostris*, mainly as PL capture in the wild) from the 29 farms surveyed is estimated at 13.5 million kg. Average total 1999 production is estimated at approx. 400,000 kg of heads-on shrimp per farm. Estimates of 1999 production of whole shrimp per farm ranged from 7,500 to 4 million kg.

The source of PL for farms by farm size category is shown in Figure 2. Fourteen (48 percent) farms stock only hatchery produced PL, four (14 percent) farms stock wild-caught PL exclusively, while the remaining 11 (38 percent) farms use PL obtained from both sources. Of farms utilizing both hatchery reared and wild caught PL, 66 percent of PL, on average, are hatchery reared; hatchery reared

PL comprised from 30 to 90 percent of total farm PL requirement for these farms. No relationship was detected between farm size and source of PL used. While the four farms that used wild-caught PL exclusively ranged in total pond area from 8 to 54 ha, farms that used PL from both sources ranged in total pond area from 23 to 3,220 ha, and farms using only hatchery reared PL ranged from 22 to 990 ha. All farms currently practice direct stocking of PL into production ponds. On two farms, nursery ponds are used to store excess capture of wild PL for stocking into production ponds as they become available. However, nursery ponds are used only for 5 to 20 percent of all PL stocked on these two farms. Final effective stocking rates of PL in production ponds range from 5 to 15 PL/m^2, putting the Honduran farms in the range of extensive to semi-intensive.

Overall, the grow-out period lasts an average of 111 (± SD) ± 17 days (d). Grow-out duration varies between rainy and dry seasons on 18 farms (62 percent). On these farms, dry season grow-out lasts an average of 115 (± SD) ± 14 d (range: 90 to 150 d) compared to a mean rainy season duration of 103 (± SD) ± 14 d (range: 84 to 130 d). Rainy season in Honduras generally occurs from May through November, while the dry season begins in December and ends in May. Grow-out duration was similar during both rainy and dry seasons on 11 farms (38 percent), and averaged 115 ± 20 d (range: 90 to 150 d).

Important factors to take into consideration when developing GMPs for the Honduran industry are seasonal changes in water temperature, PL abundance, water quality and other factors that will require changes in practices such as feeding, fertilization and water quality management. Thus, GMPs must either be broad enough that seasonal changes accommodate or specifically address the needs for management based on seasonality.

Practices related to feeding, fertilization, water quality control, health management and other operational practices are described in detail in the individual sections below.

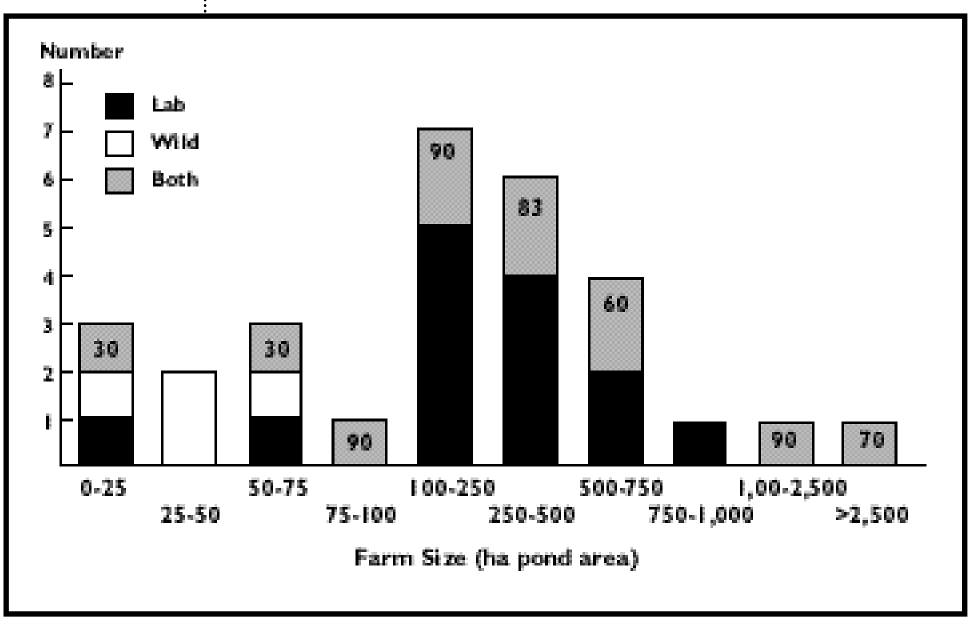


Figure 2. Histogram showing the number of farms within each farm size and the source of post-larval shrimp stocked into production ponds.
Lab=PL originate from hatcheries
Wild=PL capture from the wild
Both=PL from combinaiton of these two sources
The number shown is the mean percentage of PL required by the farm that orginated from hatchery production.

Shrimp survival for 27 farms (93 percent) ranges from 22 to 50 percent and averages 35 percent; two farm managers did not have survival data available. Managers on 21 farms (72 percent) report that shrimp survival is better during the rainy season. Survival during this period ranges from 30 to 50 percent compared with 15 to 30 percent during the dry season. Four managers feel that survival is similar throughout the year. Four other managers either have no opinion or are inexperienced because they are new at the particular farm. Managers asked to estimate what percentage of lost production results from disease respond that disease is responsible for an average of 83 percent of lost production, with other factors, e.g., management, poaching, etc., being responsible for the remainder. Responses ranged from 0 to 100 percent of lost production being attributed to disease. Historic survival rates or yields are the reference points managers cite most often in their estimates of production loss attributed to disease. These historic reference point s are either pre-Taura Syndrome Virus (TSV) or pre-White Spot Syndrome Virus (WSSV) conditions.

Historic survival rates ranged from 60 to 80 percent, while historic yields ranged from 816 to 1,134 kg/ha whole shrimp per cycle. One manager feels that yield reductions have been transitory, while another reports his reference point is comparison to other producers, and two managers did not have an opinion.

Farm managers report eight reasons for deciding to harvest a production pond. Twenty-six managers (90 percent) cite consideration of multiple criterion in deciding to harvest a pond, while three managers cite only one criterion (two cite shrimp size and one cites attainment of optimal economic returns). Shrimp size is the most common decisionmaking criterion, cited by 83 percent of the managers, followed by shrimp price (66 percent) and disease outbreak (41 percent). Remaining criterion are cited by 21 percent or fewer of all managers. While it is positive that five managers (17 percent) cite optimization of economic returns as a decisionmaking criterion, this number should be much greater. The change in management strategy has an impact on GMP development; practices that contribute to increased yield versus optimization of returns may entail important differences. On the whole, GMPs tend to favor efficient use of resources which coincides closely with the goal of optimizing returns.

Eighteen farm managers report they are responsible for decisions regarding routine farm management practices, while the remaining 11 farm managers share decisionmaking responsibilities with the company's technical director and/or technical consultant. Farm managers obtain technical information from a variety of sources including their company's technical director, technical consultants, conversations with other farm managers, international aquaculture scientific and trade literature, national and international aquaculture meetings, international industry associations, and short courses offered by the ANDAH.

Farm managers reported that on average each farm has 53 permanent employees (range: 5 to 350 employees), and a total of 1,549 people are employed permanently on the surveyed farms. Farms also employ temporary workers as the need arises; numbers of temporary workers are varied. Some estimates put the number of jobs on farms and in activities related to shrimp farming at around 12,000 (Corrales pers. comm.).

Hurricane Mitch devastated much of Central America in October 1998, including the southern region of Honduras where the shrimp industry is located. Damage to the industry infrastructure and the surrounding area was severe, although recovery was relatively rapid. Many farms attempted to restock as soon as the water level receded and damage to the ponds was repaired. The recovery effort coupled with new disease problems has significantly changed the face of the Honduran industry. The field study was conducted nine months after the hurricane, and an effort was made to capture any changes in practices or management strategy resulting in the aftermath of the hurricane.

7.0 Site Selection

Site selection, farm design and construction methods are critical considerations in shrimp farming. Many of the problems associated with aquaculture result from lack of attention to details at the planning and construction stages of an individual shrimp farming project. The GMPs do address aspects of good site selection for individual operations; but, another level of planning is required for managing entire industries to avoid problems associated with over-development when multiple operations begin to exceed the carrying capacity of the system. However, if all operations adhere to good siting practices, some level of benefit will be realized.

It is important to recognize that all land on which a shrimp pond may be built fulfills some type of function, and that all functions have associated values, whether commercial, environmental, social, or even aesthetic. Assessing the appropriateness of a given site for shrimp culture is complex if considered from an ecosystem and social perspective. There are two levels of considerations: on-site and off-site. Some of the major categories that should be considered in site selection are:

1) The suitability of a site for producing shrimp in a cost-effective and environmentally sound manner
2) The value of the site operating as a shrimp farm as opposed to its previous intrinsic value (the opportunity cost)
3) The effects on local and regional economies and societies
4) The changes in the value of other sites within the same ecosystem as a result of shrimp farming

Evaluating the suitability of a site may become complex if evaluated according to all four factors. Each site possesses a unique array of characteristics that will determine effects of producing shrimp on that site: the biological, social, environmental, operational, and financial feasibility. While some site characteristics are insurmountable obstacles (e.g., lack of access to an adequate water supply), determining the feasibility of a particular site will often require weighing the trade-offs involved in converting a piece of land from one function to another.

The role of evaluating sites according to categories 2, 3 and 4 listed above, falls principally to government regulators and resource managers because large-scale social, economic and environmental effects are beyond the domain of most shrimp farmers. Shrimp farmers can make determinations of the suitability of the site to produce shrimp (category 1), and may take into consideration some of the direct effects their operations have on producing changes, whether positive or negative, in the other categories.

This paper considers some aspects of each of these categories of criteria; but, the focus is on GMPs that influence biological suitability, while preventing adverse changes in the value of the site and surrounding ecosystem. The weight given to each criterion when determining the suitability of a particular site will vary by region, species of shrimp used for culture and method of farming (intensive, semi-intensive or extensive). Some of the major factors that must be considered in a site survey involve the topography of the site, hydrology and hydrography, and soil characteristics.

Most ponds in Honduras were built outside of mangrove areas, such as this one built to follow the natural line of the mangrove.

7.1 Topography

Farms should not be sited within mangrove forests.

Mangrove areas are widely acknowledged to be poor sites for shrimp ponds because of their ecological value, and because the bio-physical characteristics of mangrove areas tend to produce pond management problems. Construction of ponds at higher elevations avoids long-term pond management problems, lowers construction costs and allows construction of better and longer lasting facilities (McVey 1988; Poernomo 1990). In some cases, canals and pumping stations may require limited removal of mangroves. This needs careful design of the structure and mitigation through replanting of mangroves (See section 8.2).

Where possible, ponds should not be sited in riparian flood zones and preferentially should be sited in areas with the lowest risk of flooding and otherwise suitable characteristics.

Many shrimp ponds are built in flood plains so awareness of flooding patterns is critical. Flooding and erosion of earthwork and deposition of soil eroded from surrounding areas can cause loss of pond embankments, destruction of farm roads, and damage to and filling of canals with sediment. Designs should incorporate features that protect farm structures from major floods, yet not obstruct natural water flow needed to maintain surrounding habitats.

Ponds should be sited in terrain that is flat with gentle slopes (2 to 3 percent or less).

It is generally more difficult and expensive to build ponds on uneven and steep terrain. To allow ponds to be filled and drained properly at these sites, more earth must be moved and more pumps installed than at flatter sites. The cost incurred by building on a particular site should be determined during the feasibility analysis. The ability to quickly fill and completely drain ponds is essential to effective water and soil quality management (Yoo and Boyd 1994).

Whenever possible, construct ponds in areas with minimal vegetative coverage.

By constructing ponds in areas with little vegetation, construction costs are reduced, and there is less chance that the site is an environmentally sensitive area.

7.2 Hydrology and Hydrography

Site mapping should be conducted during both wet and dry season to reveal annual variation.

Engineering of structures and waterways without taking into account seasonal variations in climate and hydrology can result in costly mistakes and more severe environmental impacts. Especially critical is gaining an understanding of the hydrology of the area so there is minimal interference with the natural flow of water, yet the needs of the operation are assured. Seasonal and annual variation should be carefully studied. Damage from flooding can be prevented if flood patterns are understood (Simon 1976).

An annual water budget should be developed for the pond as part of the planning process.

The water needs of the farm must be calculated on a realistic basis, and taking into account such variables as management methods, evaporation rates, seepage rates and future plans for expansion (Boyd 1995b). Annual variation in water supply must also be considered to assure that the needs of the farm are met. Other water uses in the area must be considered to avoid conflicts with other users.

Some source of good quality freshwater should be available.

A supply of freshwater will be needed for drinking and sanitation purposes. If necessary, freshwater can be trucked onto the farm site.

Freshwater should not be mixed with brackish water or ocean water in ponds to adjust salinity.

This is a wasteful use of freshwater that is not necessary for shrimp production (Boyd 1997a).

Avoid siting farms within the normal daily tidal range.

It is generally recommended that ponds be built outside of the tidal range, which is likely to be an environmentally sensitive area. Some ponds, particularly older shrimp ponds used for extensive culture, have been designed to depend on tidal action for water exchange. This is no longer the recommended strategy because it is now recognized that high rates of water exchange are not necessary, and because ponds of this type cannot be drained and their bottoms dried easily. In other cases where shrimp ponds are built in areas such as salt flats, where high tides may occasionally inundate the ponds, engineering precautions should be taken to avoid damage to the ponds by high tides and storms. In all cases, tidal range must be considered because it influences the design of pumping and drainage systems.

7.3 Soil Characteristics

Areas with potential acid-sulfate soils should be avoided as pond sites.

Potential acid-sulfate soils contain 0.75 percent total sulfur or more (Soil Survey Staff 1994). This sulfur can oxidize to cause an extremely low pH not desirable for farming (Dent 1986). Thus, potential acid-sulfate soils should be avoided. However, moderately acidic soils can be mitigated by liming (Mikkelsen and Camberato 1995), and non-acidic, top-soil layers may be installed over highly potential acid-sulfate soils (Lin 1986; Hajek and Boyd 1994).

Organic soils should not be used for pond construction.
Organic soils are those containing 20 percent or more organic material (Soil Survey Staff 1994). Embankments are not stable if made of organic soil because the organic matter decomposes when exposed to air. Organic soils also lead to low dissolved oxygen (DO) concentrations at the soil-water interface because of bacterial decomposition of organic matter (Boyd 1992).

Soil texture should be of appropriate composition to a depth greater than that of the finished pond bottom.
The soil must have an adequate mix of sand, silt, and clay particles to provide a sufficiently low hydraulic conductivity to prevent excess seepage. It also must have a texture that will permit compaction, resist slippage, and provide stable finished embankments (McCarty 1998). A common mistake is to assume that soil must have high clay content. A soil containing only 10 or 15 percent clay with a good mix of sand and silt is much more desirable for shrimp or other aquaculture ponds than a soil with 30 percent clay or more. When pond bottoms do not have soil with desirable properties, it sometimes is possible to bring in topsoil from another area and make a layer of good soil over the bottom (Yoo and Boyd 1994; Hajek and Boyd 1994).

Soil should not contain pollutants.
Lands that have been exposed to other industrial activities, urbanized areas or those subject to run-off from agricultural areas may have accumulations of harmful chemicals or materials.

7.4 Infrastructure and Operational Considerations

Shrimp farms should be located in areas where basic infrastructure and access to business necessities are available, thus avoiding additional costs. Often, the presence or absence of desirable components is out of the producers' control. Individual business plans and feasibility studies will determine how operational necessities can be met and whether the project can reasonably proceed.

The costs and risks associated with operating a shrimp aquaculture facility have broader implications than the success or failure of an individual operation. Failed businesses have socioeconomic, and possibly environmental, ramifications. Thus, GMPs include a range of operational and business management guidelines. Consideration of these general guidelines will enhance the probability of developing a successful operation with beneficial effects.

The farm should be easily accessible year round.
Adequate access to the site either by road or water is required because tons of material and shrimp will be brought in and out of the site. In cases where roads must be built, destruction of environmentally sensitive areas may be avoided by careful planning and mitigation. A key part of this is to avoid changes in hydrology that may produce environmental impacts or damage the road.

Communication should be available by radio or telephone.
Good communications is necessary for operational purposes.

A source of high-quality formulated feeds should be available at a reasonable price.

Aquaculture feeds represent one of the highest costs to the producer. Therefore, availability of high-quality feed at a reasonable price is required for financial sustainability. Low-quality feeds or those of doubtful quality may lead to overfeeding resulting in increased effluent loading and soil management problems. A high-quality feed is not necessarily that with the highest protein-content; recent research demonstrates that use of lower protein content feed may be as effective, and they are also cheaper.

Construction equipment and supplies should be readily available.

Poorly designed and built ponds incur financial, operational and environmental costs. Reasonably priced and available supplies and equipment are fundamental to building and operating farms in a profitable manner. Detailed specifications for pond construction follow in section 8.0.

Transportation to a nearby processing facility within the time needed to keep shrimp in good condition should be available.

Without the ability of rapid, secure and cost-efficient movement of the harvest to a processing facility, there is a high probability that the operation will not be economically feasible.

A reliable source of good quality ice in sufficient quantity should be available.

Proper post-harvest handling helps ensure that premium prices are obtained and waste is reduced.

A skilled labor force should be available.

Any business operation depends on the productivity of its labor force. Availability of dependable, non-technical laborers and qualified technical personnel should be considered when selecting a farming site. A labor shortage, or the need to bring workers in from other areas, increases the likelihood of technical difficulties and social conflicts. Investment in training and developing a competent local labor force with a vested interest in the operation greatly increases the probability of success.

A reliable source of PL should be available.

A reliable source of PL is essential in maintaining production. PL are generally obtained from one or more sources: wild-caught PL, production by a local hatchery, or production by a remote hatchery. Each of these sources has associated benefits and risks as will be discussed in section 9.1.

8.0 Farm Design and Construction

A good knowledge of design principles and good construction practices can help achieve three objectives: protection of natural resources, operational efficiency, and lowered construction costs. The GAA code of practice states "the aquaculture facility shall be designed and operated in a manner that conserves water resources and protects underground sources of freshwater, that minimizes effects of effluents on surface and ground water quality, and maintains ecological diversity." Employing good practices plays a key role in minimizing or mitigating potential impacts during and after construction. Additionally, paying close attention to construction features can lower costs and improve efficiency at all stages of operation. One exception is that initial costs to accommodate specific site characteristics or to protect resources may be higher, but may be offset by reduced maintenance costs over the life of the project.

It is problematic to make specific quantitative recommendations for certain aspects of farm design and operation because factors are inter-related and dependent on numerous site-specific features. For example, there is considerable interaction between farm size, stocking intensities and water exchange rates. Choosing appropriate scales and levels requires close coordination and communication between shrimp culture specialists and construction professionals during design and construction. A degree of flexibility is also required, and setting boundary conditions in the form of GMPs should be approached cautiously. To this end, some quantitative recommendations are made in the interest of approximating reasonable targets, while recognizing that adaptive management and good judgement is required.

8.1 Layout

Buffer zone and riparian vegetation should be maintained.

By leaving the maximum amount of vegetation intact between pond areas and open water spaces, the ecological value of the area is maintained and the pond embankments are protected from erosion by tides and wind (Primavera 1993). The presence of vegetation also helps prevent runoff of sediment from the farm area into bodies of water (Brooks et al. 1997).

Traditional corridors used by local people or migrating wild animals should be maintained.

Where possible, a farm should be designed to allow access or provide alternatives to resources and migration routes that are presently in use. This may become particularly important when a large farm, or more than one farm, is planned for an area. There are claims that entire bodies of water may become nearly inaccessible to traditional resource users when surrounded by ponds.

Farm size should be in proportion to the available water supply and demand, and the estimated capacity of receiving waters to dilute, transport and assimilate effluents.

Assessing the adequacy of the water supply both to ensure adequate water exchange for the farm(s), and the ability to assimilate effluent wastes, will be dependent on numerous factors that should be assessed for each specific site. A general guideline is that effluents should not raise critical water quality parameters above standards established for the area. Use of water by the farm operation should not deprive other residents of sufficient water nor affect the ecology of the area.

Access to land or water routes, docks and staging areas should be located where mitigation of environmental impacts is possible.

It is especially important that boat traffic does not cause bank erosion. These areas are also used to transfer chemicals and fuels, so care should be taken that potentially harmful substances are not spilled into the water.

Pond alignment should consider prevailing winds to reduce erosion.

Wind and wave erosion can seriously damage embankments (Yoo and Boyd 1994), and orienting ponds so that erosion is minimized reduces maintenance costs and turbidity.

Final discharge point(s) should be located away from intake points and be placed in areas that will permit rapid dilution of pond effluents.

Care should be taken to avoid the intake of effluents, whether from the same farm or others. Avoiding discharges into stagnant or sensitive habitats where damage may occur can minimize the impact of effluents. When many farms are discharging into the same body of water, coordination between operators may be helpful in avoiding problems.

8.2 Pump Stations

Using pumps to fill ponds and ensure adequate water exchange is a major operational cost for a farm, and may also be a source of environmental damage if pumping stations are not properly sited, designed and operated.

Use multiple, efficient pumps.

Large pumps should be used because they are more efficient than smaller ones (Simon 1976). However, more than one pump should be installed on larger farms to provide for flexibility and reserve capacity. Small farms may want a backup pump is case of mechanical failure of the primary pump.

Pump stations should be located for maximum water quality and should avoid areas where environmental damage may occur.

Particular attention should be given to avoid mixing intake water with effluent from shrimp ponds or other industrial sources. Even where other industries are not present, a well-mixed, frequently flushed location in a water body is preferred as a water source. For example, headwaters of estuaries during the dry season may have reduced water quality due to reduced freshwater influx and poor tidal exchange and evaporation.

When possible, pump stations should be recessed from the bank and/or made more aesthetically pleasing.

The only sign of a shrimp pond may be the pumping station. Many shrimp ponds are located in areas that are increasingly used for tourism. Reducing visual impacts is helpful in presenting a good image of shrimp farming and reducing potential conflicts.

Removal of mangroves should be minimized when building pumping stations.
Leaving mangroves as intact as possible helps to stabilize the surrounding areas and may provide some screening of the station.

8.3 Water Supply Canals

The design and construction of water supply canals plays an important role in the flexibility of pond management, and also has an effect on reducing some of the potential environmental impacts of the operation. Water supply canals not only act as conduits of water, but may also serve to remove sediments and possibly to treat effluents. Whenever ponds are located close together, it is important to locate and design the water supply and discharge canals so that the discharge from one pond does not degrade the quality of the water supply for other ponds.

Removal of mangroves should be minimized when constructing canals and pumping stations.
Even when ponds are built outside of mangrove areas, access to water sources may only be possible by removal of some mangroves for building pumping stations and canals. Efforts should be made to design the layout of the farm so the minimum acreage of mangrove is cut. Mangrove removal should be mitigated by planting mangroves elsewhere (Field 1996).

Canals should be designed to minimize erosion by rainfall and to prevent scouring of channel sides and bottom by flowing water.
Standard design procedures that consider soil properties, slope, water flow rate, best hydraulic cross section, and other factors should be used (Wheaton 1977; Yoo and Boyd 1994).

Canals should not create barriers to natural flows of water.
Altering natural watercourses may impact sensitive areas, and flooding or erosion will damage the canals themselves. Surveying the area and studying the hydrology of the area prior to construction will allow assessment of where natural watercourses are at risk. Adjusting the layout of the farm, providing adequately sized culverts under roads, or limiting diversion of waterways around structures with discharge back into the original waterway will prevent alteration of natural flow.

If canals pass through freshwater or agricultural areas, they should not seep and cause saline water intrusion.
Seepage can be limited by avoiding sandy or gravelly areas, or lining the canal in areas where the hydraulic conductivity of soil is high. Soil testing will be required in areas where canals are planned. Intelligent design can limit the length of canals, which both reduces costs and minimizes seepage.

Settling basins should be built at the head of intake canals to allow for settling of the sediment load before water enters the ponds.
Estimates of the sediment load of incoming water and the needed dimensions of a settling basin should be calculated and incorporated into the design by an experienced engineer (Boyd 1995a). Testing may be needed to determine the required residence time necessary to

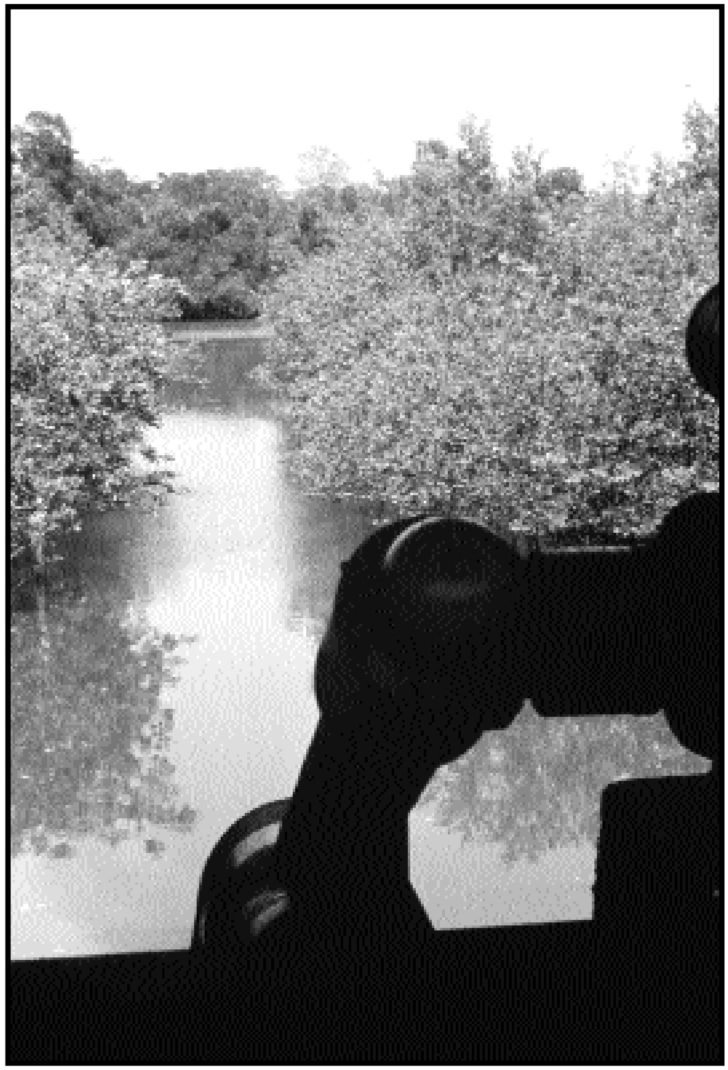
remove a significant amount of the suspended solids. The use of two settling basins within the same intake system should be considered because one can be cleaned while the other continues to function.

Intake canals and the water distribution system should be designed to allow the water to flowby gravity.
If proper engineering methods are used to provide enough slope for water to flow by gravity, the need for additional pumping stations within the system is minimized. This reduces power consumption, additional construction and operation costs.

8.4 Pond and Embankment Construction

Good pond construction will play a major role in nearly all management aspects of a farming operation. Poorly designed and constructed ponds incur high maintenance costs, put the crop at risk, make management more difficult and less profitable, and negatively impact the environment. Since shrimp ponds are often built in low lying, coastal areas, they are particularly vulnerable to natural disasters such as floods and hurricanes. Environmental impacts of poorly designed and built ponds may include excessive water requirements, poor water quality, and increased outputs of suspended solids. Construction practices are listed below that will aid in building long-lasting structures, increase the ease of management and leave no lingering adverse effects. Good construction and siting practices will help reduce damage from some natural disasters.

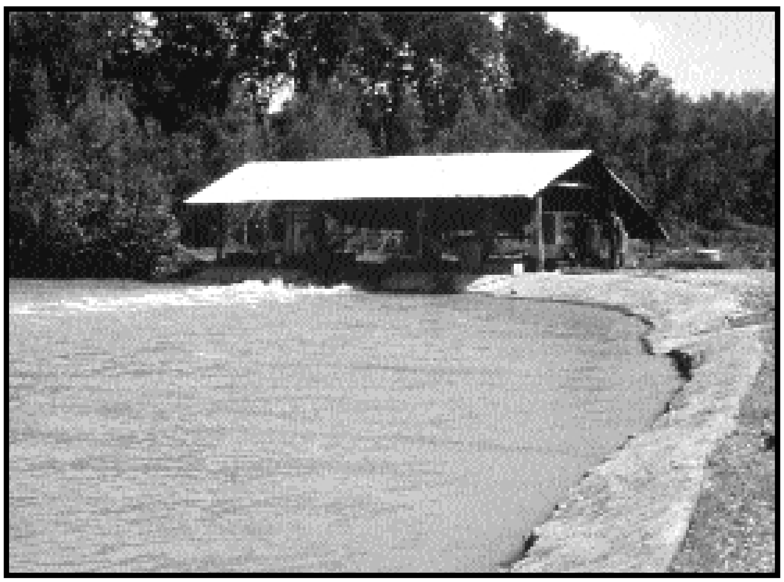
A qualified engineer should be consulted for planning, and an experienced contractor should be engaged for construction.



Care has been taken to only cut a very narrow opening in the mangrove fringe to allow for pumping. Construction of this shrimp farm did not otherwise involve cutting mangrove. This also helps reduce visual impacts.

Qualified personnel who have experience building aquaculture facilities will use good construction practices. To the greatest extent possible, local workers should be hired and trained in construction skills. Where this is not possible, qualified personnel should be brought in to assist with training and to provide oversight of the project.

Drainage canals require good construction, stabilization and maintenance to prevent erosion.



Drainage canals with sloped banks and stabilizing yet well-trimmed vegetation such as these mangroves will not have erosion problems.

To prevent seepage under pond walls, the ground should be completely cleared of vegetative matter and the walls sealed to the existing soil by compacting.

Seepage under pond walls prevents proper drainage and drying, thus decreasing pond productivity over time. Removing all vegetation before installing and compacting the embankment soil will permit the walls to fuse to the ground and seal the pond.

Embankments should be sloped and compacted in relation to soil particle size characteristics (texture) to reduce erosion, seepage and slip.

Outside slopes with no water contact can have a slope as steep at 2:1, but inside slopes and those exposed to water should be no steeper than 2.5:1. Standard soil engineering texts such as McCarty (1998) provide guidelines on slopes for different soils.

Embankment height should be high enough to prevent damage from floods, storms or waves, but freeboard should be limited so that winds can mix pond waters.

Embankment freeboard should be at least approximately 0.5 m to allow winds to mix pond waters.

Embankment width should be at least 2.5 m wide, and 3.7 m or more if used as roads.

Embankments which are not of adequate width or are weak because of loose, poorly compacted soil may leak or breach. This causes economic loss due to increased maintenance requirements and loss of the crop. The environmental consequence will be release of domestic shrimp into the wild population.

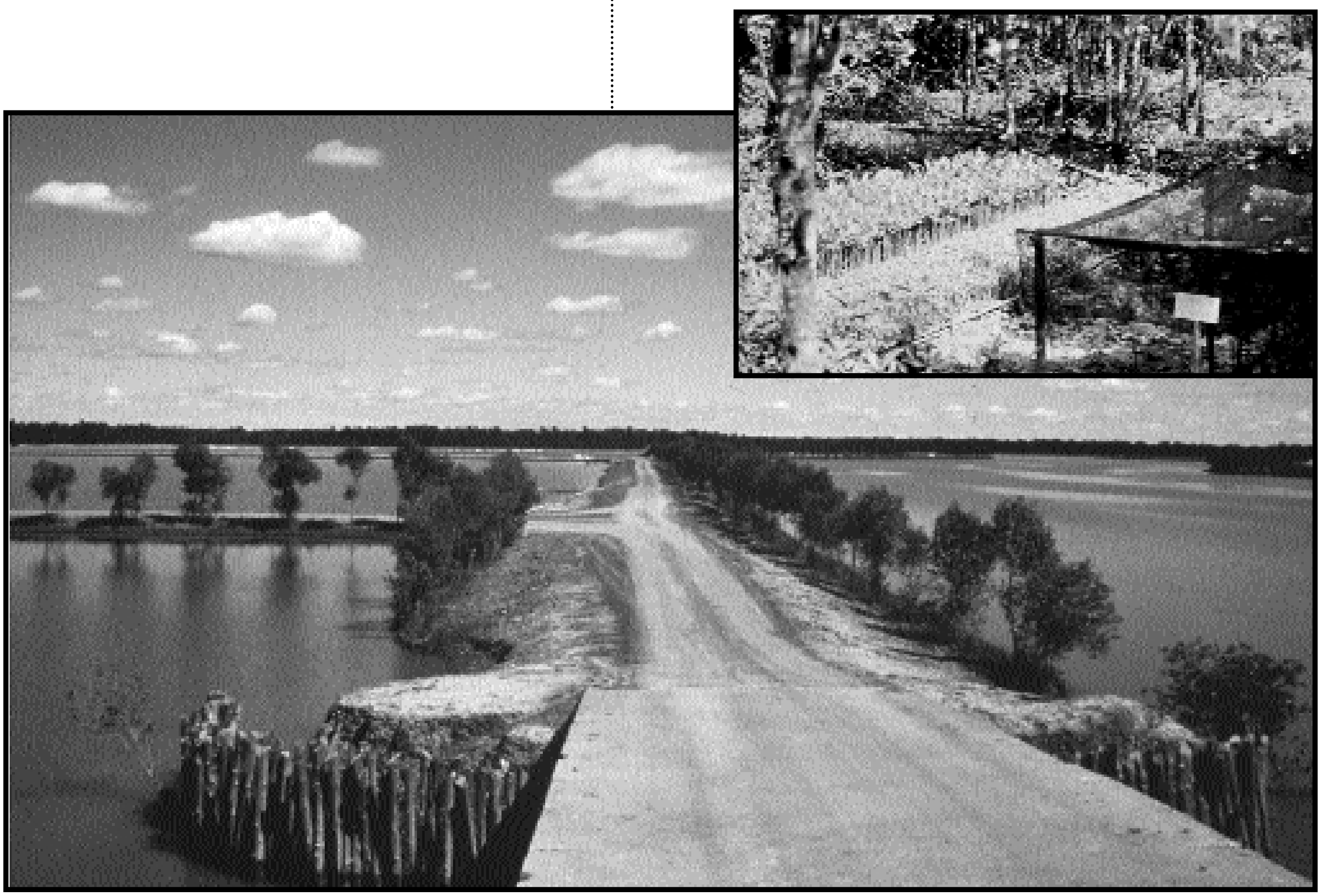
Continuous erosion or breaching of embankments may add to the suspended solids load going into environmentally sensitive areas.

Embankments should be well compacted during construction.

The standard Proctor test or some variation of this test is useful in determining compaction requirements (McCarty 1998).

Pond bottoms should be smooth and sloped to allow sufficient drainage so the pond can be completely dried.
Complete drainage is essential for rapid harvest and to allow bottom soils to be dried between crops (Boyd 1995a). Where complete drainage is not possible, auxiliary pumps may be used to empty ponds for harvest. This increases harvest time and energy consumption. The average slope should be 0.5 to 1 m per km to permit rapid draining. Restocking of a pond that has not been completely drained and dried can foster disease transmission between crops and lead to reduced soil quality (Boyd 1995a).

Ponds should be shallow enough to allow easy management and good circulation of water, yet deep enough to prevent plant growth.
Ideally a pond should be about 1.0 to 1.2 m deep at the shallow end and 1.5 to 2.0 m deep at the drainage end. When ponds exceed this depth, it is less likely that the wind will provide sufficient internal circulation to



Mangroves often colonize pond areas. They can be planted where necessary to reenforce pond banks that are eroding. Some shrimp farmers have started mangrove nurseries (inset) for reforestation or other planting purposes.

prevent anoxic or hypoxic conditions at the pond bottom. Toxic substances resulting from the lack of oxygen near the bottom of the pond where wastes accumulate can damage the shrimp and produce water quality problems (Boyd 1995a). Very shallow water permits enough light to penetrate to the pond bottom to encourage benthic plant growth. There is no productive advantage to deeper ponds and, because construction and maintenance are also higher, there is no economic advantage.

Fuel tanks and other containers with hazardous materials should be surrounded by retaining walls in case of spills.

A concrete retaining structure should be built outside the pond walls on the lower end of the pond to make harvesting easier. Such a structure facilitates harvest by collecting shrimp in a concentrated mass and helps complete drainage of the pond. Shrimp harvested in this manner will be of higher quality since they will be less likely to pick up an off-flavor (Lovell and Broce 1985).

Taking into account local hydrological features and managing local water flows should minimize erosion, runoff, and construction difficulties.

Construction requires dry conditions if proper construction methods, such as adequate compaction of embankments, are to be used. This is accomplished by building in the dry season and making provisions to divert runoff from surrounding areas. At the same time, attempts should be made not to interfere with the water supply to sensitive surrounding areas or local residents. Sediment-laden and contaminated runoff from the construction site should be prevented from entering local waters without first passing through settling basins or buffer areas. Again, a hydrologic survey in both the wet and dry season can provide information allowing planners and operators to manage water flows at the construction site.

Access roads should have adequately sized culverts installed to prevent impoundment of freshwater and/or alteration in brackish water flow.

Raised roadbeds are often necessary in areas where shrimp ponds are built. Unless drainage in the form of adequately sized culverts are built into the roadbed, the raised road may act as a dam and cause flooding. This may cause the road to be washed out.

Differing soil characteristics should be considered in building earthwork, and construction techniques should be modified within the construction area as necessary.

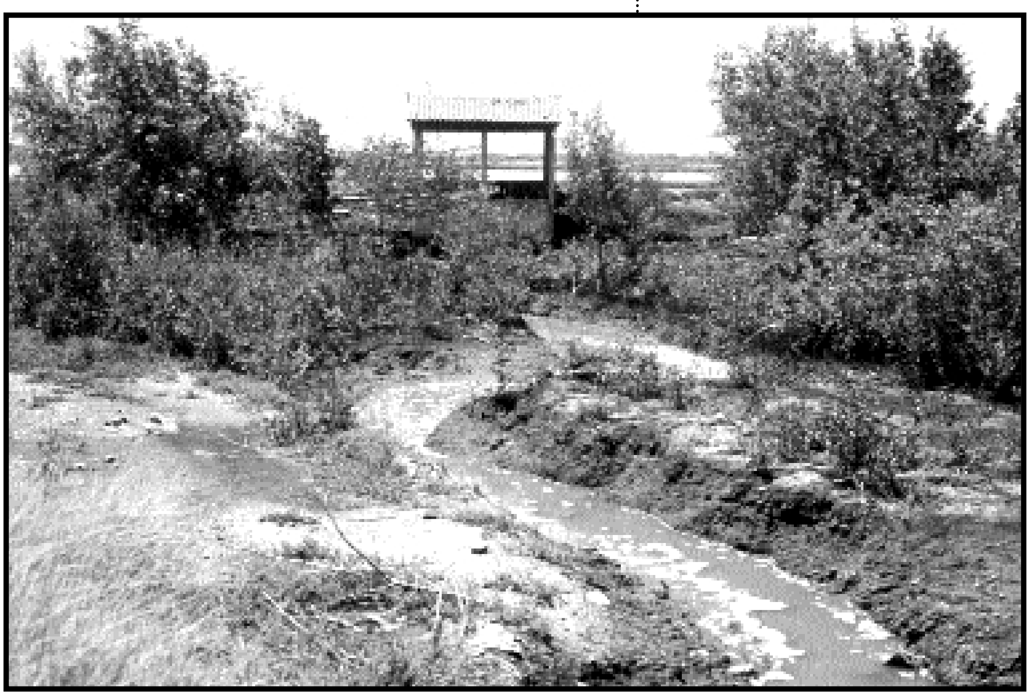
Soil properties may vary within the site; thus, soil testing throughout the site is needed during the planning stages, and the layout should be adjusted accordingly. A qualified engineer and skilled construction crew can then construct proper earthwork features such as embankments, canals, and roads.

Growth of vegetation on the upper portions of canals and embankments that are above water level should be encouraged where possible.

Topsoil removed during pond construction should be stored temporarily and spread on parts of canals and embankments that are above water to encourage the growth of a suitable vegetative cover. A suitable vegetative cover crop consisting of salt-tolerant species should be established on the exposed areas of canals and pond levees to prevent erosion. Vegetation often establishes slowly on subsoils; thus, reuse of topsoil on embankments provides a better soil substrate for plant growth. In some cases, lack of freshwater may make it difficult to establish vegetative covers such as grass. If care is taken that water supplies are not blocked or the structural integrity of the embankments is not threatened, mangroves may be allowed to colonize along canals and embankments to stabilize these structures. In some cases, however, high salinity or lack of freshwater during the dry season may inhibit or prevent growth.

Fuels and lubricants should be stored and used in a manner that prevents spills.

Containment basins should be built around all fuel storage depots to provide protection of adjacent areas in case of a spill. Protocols to be used in case of a spill should be developed for each operation.



The pumping station is situated where water volume is low and may be of poor quality.

Farm HAACP plans should be implemented for all materials.

This requires labeling of all fuels, lubricants, and chemicals; and a technical specification sheet for each product should be available to explain the proper storage and use on the site (USDA 1995).

All waste material should be removed from the site and disposed of responsibly once construction is complete.

Ways of removing waste materials will vary according to the type of waste and the local situation. Organic wastes can be composted or buried. Wastes from shrimp processing can be made into meal or composted. Inorganic waste can be incinerated or buried in sealed pits. In the case of hazardous wastes such as chemical, spent fuel, paint, etc., local regulations and procedures should be investigated and followed. Where none exist, technical assistance should be sought.

8.5 Discharge and Intake Canals

Proper design of discharge and intake canals prevents environmental damage by minimizing impacts on the surrounding ecosystem and by aiding in better pond management.

Inflow and outflow structures should be installed in each pond for controlling flow.

These inflow and outflow structures should be sized to allow for prompt drainage (1 to 2 days) and rapid filling (3 to 4 days). The apertures should be screened to prevent entrance of other organisms and to prevent the escape of shrimp. The screens should be cleaned daily.

Canals should not create barriers to natural flow of water such as streams or rivers.

See section 8.3 for full explanation.

Sediment traps or settling basins should be built in discharge canals to allow for removal of suspended solids from effluents.

Removal of suspended solids by passive methods is inexpensive and may greatly improve the quality of the effluent. Methods of removing suspended solids are still experimental and will require testing and some design expertise to be effective.

Effluents should never be discharged into freshwater or agricultural areas.

Saline effluents can be discharged only into bodies of saltwater without risking saline intrusion and salt accumulation. Discharges into freshwater can permanently damage valuable land or contaminate freshwater needed for other purposes (Primavera 1993; Boyd 1997a).

9.0 FARM OPERATION

Efficient farm operation is essential for environmentally sustainable and profitable shrimp farming. Economic efficiency and reduced environmental impact are linked. Efficient production means less waste, subsequently, lowered probability of environmental impacts. Farm operation GMPs address various ways of reducing waste in most stages of shrimp farming, and thus provide multiple benefits of lowering costs and maintaining environmental quality.

The majority of the GMPs presented here are intended as general guidelines or strategies that must be adapted according to the conditions found on each farm. Farm managers will need to constantly monitor the results of their operational practices and make modifications accordingly. Each farm should develop an operational plan based on a monitoring plan and the GMPs presented below. Good record keeping is a must if results are to be tracked and analyzed.

9.1 SOURCE OF POST-LARVAE

Success of an individual operation and the viability of a regional industry will be determined by having a reliable source of PL. The mass production of affordable, high-quality, viable PL is the key to modern shrimp aquaculture (Boyd and Clay 1998).

The two principle sources of PL are wild capture and hatchery production. Both sources offer certain benefits and potential impacts. Use of hatchery PL will reduce capture of wild PL and associated by-catch, thereby protecting biodiversity. However, this is not to suggest that development of hatcheries and use of hatchery-produced PL will not have social, economic and environmental ramifications. Proper protocols are required if hatcheries are to be operated without adverse environmental effects. Although the global industry increasingly relies on hatchery PL, the economic welfare of many people depends upon capturing wild PL to sell to shrimp farms. Thus, greater reliance on hatchery PL will have social and economic effects.

Full discussion of hatchery technology and its effects is beyond the range of this paper, but several basic GMP recommendations are made that may avoid some most severe problems associated with the sources of PL.

Target culture species should be limited to those that are endemic to the area, and which have been historically used in commercial aquaculture operations.

Introduction of new species of shrimp should be avoided. Potential negative effects associated with the introduction of exotic species include competition with native organisms, introduction of disease, changes in the food web or modification of habitats (Courteney 1992).

PL produced in domestic hatcheries should be preferentially used.

Using locally produced PL offers the advantages of preventing the spread of disease, providing local employment, and reducing PL losses and costs. Where local hatcheries are not available or where production is insufficient for the industry, wild-caught PL may be used. In cases where wild-caught PL are used, care must be taken to use fishing methods that do not unnecessarily affect the populations of other species found in estuaries. As for all fisheries, the PL fishery in each area should be managed under a fisheries management plan. When wild larvae are captured, the by-catch in nets should be quickly returned to the water (Boyd and Clay 1998).

Domestication of shrimp should be encouraged. Increasing availability of hatchery facilities and improved hatchery technology will make domestication of shrimp for aquaculture purposes feasible. Efforts in this direction have already produced benefits for the industry in the form of specific pathogen resistant (SPR) and specific pathogen free (SPF) strains. Domestication of shrimp holds the promise of improving production efficiency and avoiding waste. Domesticated strains could be produced that are more genetically fit to thrive under culture conditions. An example of this might be strains that could grow rapidly using feeds with low protein content. Ensuring a reliable supply of healthy PL throughout the year would help stabilize production and give managers more options for better farm management. The wild-PL fishery, like most fisheries in developing nations, has proven difficult to assess and manage. Hatcheries can be built and managed under controlled conditions thereby producing a source of PL with few, if any, environmental impacts and many benefits.

Comparative Characteristics of Hatchery and Wild-Capture Postlarvae Production for Consideration in Formulating GMPs

Hatchery production and the wild-capture fishery are practiced in a variety of ways throughout the world. Both may be used as a source of PL within a region where shrimp farming is practiced. Rigorous quantitative documentation of the scope and intensity of the benefits and impacts is insufficient to make definitive statements about GMPs that are applicable to the industry as a whole. The comparison of advantages and disadvantages of the two sources highlights some issues that should be taken into consideration when formulating GMPs for the industry. It should be noted that the characteristics listed below will vary geographically, and very little research exists to evaluate these in the Honduran context.

Hatchery Production	Wild Capture
Advantages	**Advantages**
Allows domestication of stocks, i.e., optimization of desired culture traits	Offers employment, especially to marginalized peoples
Steady, year-round supply	Use of native species
Production of SPR or SPF strains	PL may be less expensive
Quality control possible	Permits shrimp culture in areas without hatchery capability
No by-catch	Higher survival rates
Produces only desired species	
Provides employment	
Disadvantages	**Disadvantages**
Introduction of exotic species	By-catch
Alteration of genetic characterization of native strains possible, but demonstrated	Effluents from hatchery
PL may have lower survival rates	Results in capture of several non shrimp species
Displacement of PL fisheries	Poor handling may cause stress and loss
Unknown effect on shrimp stocks	Irregular supply
If wild broodstock is used, wild stocks can be overexploited	PL may be more expensive
	Use of child labor in some cases
	May be more expensive

Honduran Industry Practices – Source of Post-Larvae

Fourteen (48 percent) of the 29 farms stock only hatchery-produced PL, four (14 percent) farms stock wild-caught PL exclusively, while the remaining 11 (38 percent) farms use PL obtained from both sources (Figure 2). Of farms utilizing both hatchery-reared and wild-caught PL, 66 percent of PL, on average, are hatchery reared; hatchery-reared PL comprise from 30 to 90 percent of total farm PL requirement for these farms.

No relationship was detected between farm size and source of PL used. While the four farms that used wild-caught PL exclusively ranged in total pond area from 8-54 ha, farms that used PL from both sources ranged in total pond area from 23-3,220 ha, and farms using only hatchery-reared PL ranged from 22-990 ha total pond area.

All farms currently practice direct stocking of PL into production ponds. On two farms, nursery farms are used to store excess capture of wild PL for stocking into production ponds as they become available. However, nursery ponds are used only for 5-20 percent of all PL stocked on these two farms. Final stocking rates of PL in production ponds range from 5-15 PL/m^2, putting Honduran farms in the range of extensive to semi-intensive culture.

Honduran farms are therefore in general alignment with the recommended GMPs because local species are used. The choice between hatchery-produced or wild-caught PL depends on a variety of factors related to supply, availability and price. There are no indications that the wild-PL fisheries produce environmental impacts; this artesianal fishery offers economic benefits to the local population.

I

Importation of PL should be in accordance with applicable national regulations governing imports. In the absence of suitable regulations, international guidelines should be followed.

Importation of PL poses numerous environmental and financial risks. These risks involve the spread of disease, introduction of exotic species or genetically different strains, mortality during transportation, and possibly lack of availability at critical times. When PL are imported, Office International des Epizooties guidelines should be followed (Office International des Epizooties, World Organization for Animal Health 1995), or as in the case of Honduras, OIRSA regulations.

Before stocking, PL should be examined for signs of disease and to assess quality.

Regardless of source, PL should be examined by qualified personnel for signs of disease. Stress tests may also be done to determine their hardiness (Clifford 1994). If results are outside of normal parameters, the PL should not be stocked. These PL should be destroyed and the holding water disinfected with chlorine or other suitable disinfectant.

9.2 Pond Preparation

Pond bottoms should be dried completely, at least after three or four production cycles, and more frequently is advisable.

The pond should be dried until the bottom develops cracks approximately 5 to 10 cm in depth. This serves to oxidize reduced substances and accelerate decomposition of organic matter. The drying cycle is especially important for oxidizing and detoxifying inorganic sulfides present in pond soils. Drying will also kill pest organisms.

HONDURAS INDUSTRY PRACTICES – ASSESSMENT OF SHRIMP POST-LARVAE HEALTH

Both adult and juvenile shrimp are tested for the presence of pathogens. Six viral or bacterial diseases are commonly reported in Honduran shrimp (Table 5). Shrimp health management practices implemented on surveyed farms are detailed in Table 6. Fourteen (48 percent) farms currently are having PL analyzed for white spot syndrome virus (WSSV) by PCR test. Generally, these farms require that PL suppliers, especially from outside Honduras, provide PCR results for shipments of PL from their hatcheries. These farms also occasionally will evaluate using PCR shrimp suspected of being infected by WSSV; however, these samples must be sent to laboratories in Tegucigalpa or the United States. It is expected that the frequency of PCR analysis for WSSV will increase when ANDAH installs its PCR equipment in its shrimp pathology laboratory in Choluteca. Sixteen (55 percent) farms use the dot-blot test for WSSV; three of these farms first run the spot-on test, running the dot-blot for WSSV and infectious hypodermal and hematopoietic necrosis virus (IHHNV) only after a positive spot-on result. The remaining 13 farms do not use dot-blot for WSSV. Only five (17 percent) farms use dot-blot to diagnose Taura Syndrome Virus. Thirteen (45 percent) farms also diagnose IHHNV using the dot-blot test. Nearly all (90 percent) of farms conduct some sort of evaluation of shrimp health at least weekly. This evaluation can involve macroscopic field exams for gross symptoms of any of the diseases, to weekly histopathological laboratory exams conducted by a microbiologist. Farms often combine field and lab evaluations in their shrimp health management plan.

Two sites in Honduras currently are capable of performing the PCR test: the National Autonomous University of Honduras and a private diagnostic laboratory, both of which are located in Tegucigalpa. Some farms also send samples for PCR analysis to the United States. The ANDAH aquatic pathology laboratory, located in Choluteca, is in the process of installing its own PCR equipment and should be ready to begin performing analyses by the end of September 1999. Given the ANDAH laboratory's central location to the shrimp industry, high demand for PCR analysis for WSSV is expected once its equipment is installed.

Stocking healthy PL is another component of shrimp health management practices. In addition to the above PCR/dot-blot tests and field/laboratory exams, on 52 percent of the farms surveyed, PL are subjected to a stress test prior to stocking. Stress tests often were performed at local hatcheries or acclimation centers off-farm, before PL were transported to the farm for stocking. A sudden decrease from ambient salinity to freshwater (0 ppt) for a period of 15-30 minutes before salinity is returned to ambient salinity (nine farms), and being dipped into a formalin (100 mg/L) solution for 30 minutes (three farms) are the two most common stress tests. Either samples of PL or the entire population are subject to the stress test. Subjecting a sample of PL to crowding for 24 hours or a sudden increase in water temperature from 22 to 28 degrees C were the other two stress tests reported. Stocking of PL into production ponds on all farms takes place at the coolest time of day, i.e., pre-dawn hours; the acclimation process involves adjusting slowly the salinity and temperature of transport water to those of the production pond. The process is monitored closely by technicians to ensure that PL do not become stressed and that dissolved oxygen concentrations remain high at all times.

Honduras Industry Practices – Assessment of Shrimp Post-larvae Health, Cont.

Most managers attempt to either screen or test PL for disease, indicating that the industry recognizes the importance of these practices. Gaps exist in the number of farmers who do not conduct these tests, variability in the number and range of tests performed and the availability of laboratory facilities in the immediate area. Although samples may be sent to Tegucigalpa or the U.S., this is costly, time consuming and may interfere with timely restocking of ponds. Improving this situation may be a matter of training in some cases, but making laboratory facilities and trained personnel available in southern Honduras will help farmers implement these tests.

Post-larvae should be slowly acclimated in the hatchery before transport to the farm in order to lower stress for the post larvae and to minimize acclimation at the pond side.

9.3 Stocking Density

Determination of stocking densities is one of the most critical decisions that a farm manager can make. From the perspective of maximizing production efficiency, the objective is to harvest the highest density of a specific size shrimp without increasing per-unit costs. From an environmental perspective, managing stocking densities will revolve around reducing inputs into the pond, and thereby reducing outputs in the form of wastes in the effluent.

The stocking rate depends on a number of factors such as the expected mortality rate, ability to manage water quality, PL cost, and other operational costs. Maximum stocking rates for semi-intensive culture will be those that can be maintained without aeration and excessive mortality. Excessive stocking and feeding rates lead to poor water quality that stresses shrimp and makes them more susceptible to disease. Effluent quality tends to deteriorate as feeding rates increase (Dierburg and Kiattisimkul 1996). Determination of an appropriate stocking density depends on water quality, pond design, water exchange rates, possibility for mechanical aeration, staff expertise and overall technical capacity. GMPs provide guidelines that may help determine reasonable ranges, rather than absolute limits, for stocking rates for semi-intensive culture that result in profitable harvests while attempting to minimize effluent loads.

The desired stocking density should be determined based on survival and carrying capacity.

The maximum stocking rate is highly site dependent. The typical mortality rates of each area should be taken into consideration because high mortality from disease may require initially high stocking rates as compensation. The carrying capacity of individual ponds, based on DO concentrations, productivity, soil and water quality, will also help determine the stocking rate. Producing more frequent crops of smaller shrimp or fewer crops of larger shrimp are management options that need to be considered in relation to total revenues and potential environmental impacts.

For semi-intensive ponds without mechanical aeration, stocking densities at harvest should generally be in the range of 10 to 15 shrimp/m^2.

The final stocking density of shrimp in a semi-intensive pond without mechanical aeration will generally not exceed this number due to constraints presented by DO levels and carrying capacity. Exceeding this range will generally require use of higher feed input that will result in abundant phytoplankton growth and oxygen depletion unless mechanical aeration is used.

9.4 Feeds and Feed Management

Shrimp nutrition is based on a variety of organisms (e.g., algae, small benthic invertebrates, and organic detritus) that are part of the natural productivity and manufactured feed provided by the farmer. Manufactured feed is a direct source of nutrients to shrimp, but nutrients in feed that are not converted to shrimp flesh enter the water and fertilize the pond (Boyd 1990). In semi-intensive culture, feeding rates are usually low enough that this should not be a problem. Problems could occur, however, when the farmer moves towards intensification. Higher feeding rates could lead to abundant phytoplankton levels and high oxygen demand at night. Providing more feed than the shrimp consume could contaminate the pond bottom with decaying feed and possibly deteriorate bottom soil quality.

Natural productivity is important in shrimp ponds. This is true especially in the early stages of PL growth. Using

Honduran Industry Practices – Pond Preparation

About 59 percent of farmers dry pond bottoms. This is mostly done during the dry season. Sterilization of pond bottoms through application of lime is also attempted by most farmers when the pond is drained, although this is not practiced in the most effective manner.

Honduran Industry Practices – Stocking Density

All farms currently practice direct stocking of PL into production ponds. On two farms, nursery farms are used to store excess capture of wild PL for stocking into production ponds as they become available. However, nursery ponds are used only for 5-20 percent of all PL stocked on these two farms. Final stocking rates of PL in production ponds range from 5-15 PL/m^2. This stocking rate puts Honduran farms in the category of extensive to semi-intensive. Historically, Honduran operators have attempted to keep stocking rate relatively low on the theory that this avoids the need for excessive inputs of feeds and fertilizers and helps protect against the disease epidemics that were observed in Ecuador and Asia.

Shrimp should be sampled frequently and feed adjusted to biomass.

fertilizer can stimulate natural productivity when feeding rates are low. However, later in the crop, feed inputs

will be greater, and fertilizer nutrient inputs should be reduced to protect water quality (Boyd 1990). Production will be low in fertilized ponds without feeding. There-fore, it is more efficient to use manufactured feed and increase production per unit area.

The feeding regime should take the following recommendations into account:

A high-quality, pelleted feed with a minimum of fine particles should be used.

Pelletized food should be formulated to retain its shape for several hours so it remains intact for the shrimp to eat. Feed that disintegrates rapidly cannot be consumed by the shrimp. It also fouls the soils and leads to water quality deterioration.

Fish should not be used as feed.

Use of fish as feed causes more water quality problems than does formulated feed and may transmit disease.

Feed should be stored in cool, dry buildings safe from pests.

In order to protect feed from pests and becoming moldy, feed should be stored in a dry place. If feed does become moldy, it should never be used in ponds (Brunson 1997).

Nitrogen and phosphorus levels in feed should be as low as possible without sacrificing feed quality. Caution should be exercised because lower limits for these compounds are still unknown.

Nitrogen and phosphorus are expensive in feed, and in excess they cause eutrophication in ponds and waters receiving pond effluents. Therefore, feed should not contain more nitrogen and phosphorus than necessary for shrimp requirements. Much research is still needed in this area, but farmers may want to experiment with feeds containing lower amounts of these compounds on a small scale to determine levels appropriate for the individual farm. In areas where feed quality is not guaranteed by vendors, feed should be analyzed by independent laboratories to verify its content. This will assist by keeping feed contents at desired levels, and in calculating feeding rates.

Efficient application of feed entails attention to the following:

Feeds should be used to derive the maximum benefit while lowering costs and potential impacts.

Feed requirements should be calculated based on regular biomass estimates and feeding formulas.

Feeding requirements will vary as shrimp grow and with the level of natural productivity in the pond. Feeding rates can be roughly calculated based on standard tables, but they must be adjusted weekly according to the growth rate in individual ponds. Judicious use of feed requires regular sampling of shrimp growth and monitoring of pond conditions. In addition, the feeding calculations should include compensation for expected mortality. Many farms have developed expected mortality curves for the grow-out cycle.

Consider using feeding trays to monitor feeding activities.
Feeding trays provide a simple way to determine how well shrimp are eating and to avoid overfeeding. Proper feeding will reduce cost and protect pond soil and water quality. Shrimp do not eat well when stressed by disease or poor environmental conditions. Thus, feeding trays provide a biological monitor of environmental conditions in ponds. Some farmers are experimenting with offering all feed on feeding trays. The benefits and cost-effectiveness of this method has not been established.

Disperse feed uniformly over the pond surface avoiding large, repeated applications over small areas.
Large applications of feed in small areas may lead to piles of uneaten, decaying feed that causes deterioration of soil quality. Shrimp can find feed easier if it is offered in many places, e.g., broadcast uniformly over ponds or distribute on feeding trays throughout the pond.

Apply daily feed allowance in more than one application per day where possible.
This permits better utilization of feed by shrimp with less waste.

Do not feed when DO concentrations are below 2.5 mg/l.
Feeding is inhibited when DO concentrations fall

Applied Research in Reducing Protein Content in Feeds on Honduran Shrimp Farms

Benefits

Lowering protein content in feeds could have multiple benefits. High protein feeds are a major cost in shrimp production. Reducing protein content, a source of nitrogen, lowers nitrogen inputs into ponds. Typical shrimp feeds may contain 30 percent to 40 percent protein. Because the principle source of protein in aquaculture feeds is fish meal, reducing protein content helps protect other marine resources, making shrimp an environmentally, as well as nutritionally sound dietary choice.

Complexities

Determining how far protein levels can be reduced without damaging the crop is complex because there are many factors that determine how shrimp feed and how they utilize dietary protein. Shrimp metabolism and other pond dynamics that affect shrimp nutrition are affected by factors such as season, species of shrimp, temperature, water quality, type of protein, feed characteristics and many other factors. These vary greatly between individual farms and regional industries. Research focused on optimizing feed efficiency must take these site-specific factors into account.

Current Status of Research

The Honduran shrimp industry (ANDAH), in collaboration with the Auburn University, PD/A CRSP has researched this in pond trials under conditions appropriate to the local industry.

Semi-intensively managed shrimp ponds in Choluteca, Honduras, were stocked with 5 to 11 juvenile *P. vannamei* per m^2. Shrimp at each stocking rate were fed a 20 percent or 40 percent protein content feed six days per week. The experiment was repeated during the rainy and dry seasons. Shrimp yield, mean weight of shrimp, feed conversion ratio and water quality variables were not affected by dietary protein content during either experiment. Thus, protein content of formulated rations for semi-intensive culture of *P. vannamei* can be reduced to 20 percent (Teichert-Coddington and Rodriguez 1995).

HONDURAN INDUSTRY PRACTICE – FEED MANAGEMENT

Shrimp feeds contain 20-25 percent crude protein. Twenty farm managers (69 percent) use a 25 percent protein ration as their primary feed, while eight managers (28 percent) primarily use a 20 percent protein feed. Three managers that use a 20 percent protein ration as their primary feed also use a 25 percent protein feed to "push" the shrimp when growth samples indicate growth has stagnated. Likewise, three managers that use a 25 percent protein feed as their primary ration also used a 30 or 35 percent protein feed to "push" the shrimp. One manager uses a 22, 25, 31, or 35 percent protein feed depending on shrimp growth. The majority of farm managers (83 percent) use the same feed throughout the year. Four farm managers (14 percent) use feed with higher protein content or higher percentage of animal protein during the rainy season. Shrimp feed is stored on average 21 days (SD ± 15 d; range: 0-60 d) prior to use. Feed is checked for mold prior to use on 28 farms (97 percent), and moldy feed is not used at all on 26 farms. Three farm managers have used moldy feed, damaged as a result of Hurricane Mitch, as pond fertilizer.

Shrimp feeding rate is adjusted based on shrimp biomass in ponds on 28 farms (97 percent). Pond shrimp biomass is estimated by sampling the population for average individual weight and adjusting initial population for mortality. Only one farm manager bases feeding rate on consumption as measured with feeding trays. Shrimp growth in ponds is monitored on a weekly basis on 28 farms and on a biweekly basis on one farm (Table 2).

Growth samples begin an average of 24 days after stocking, while population samples begin an average of 36 days after stocking. Population samples are used to estimate a pond's shrimp population and are conducted on 28 farms using cast nets. The procedure involves determining the mean number of shrimp captured in an average of nine cast net throws per hectare, multiplying this number by the ratio of pond area to cast net area, multiplied by an empirically derived correction factor. Several farm managers also use empirically derived mortality curves in combination with population sample results, while one manager uses only mortality curves to adjust shrimp numbers in ponds.

TABLE 1.
SHRIMP PONDS SAMPLING SCHEDULE FOR MEASURING SHRIMP GROWTH AND POPULATION GROWTH.

Sampling for	Number of Farms	Days After Initial Stocking, (mean ± SD)	Range	Frequency of Subsequent Sampling, Days (mean ± SD)	Range
Growth	29	23.8 ± 8.7	1-40	7.2 ± 1.3	7-14
Population	28	35.6 ± 7.7	20-45	15.5 ± 4.6	7-24

Farm managers follow one of two general feeding strategies: offering feed beginning one to seven days after stocking or three to six weeks after stocking. Where feed is offered at stocking, small amounts of feed (2-6 kg/ha) are offered daily to every other day until the first growth sample is taken, at which time feed rate is calculated based on shrimp biomass. Pond feeding crews are actively supervised on all farms. Where initiation of feeding is delayed three to six weeks, feed ration is always based on shrimp biomass. Shrimp derive nutrients for growth from natural productivity during this initial three to six-week period. Pond fertilization stimulates natural pond productivity that substitutes for commercial rations. Feed is first offered to shrimp on all farms a mean of 15 days post stocking (Table 2). Only 22 farm managers (76 percent) know the feeding rates they use on farm. The remaining farm managers rely on the farm technical director/ consultant to provide this information. Mean initial feeding rate is 12 percent of daily shrimp biomass, decreasing to a mean of 2.4 percent of daily shrimp biomass just prior to harvest (Table 2).

TABLE 2.
FEEDING PRACTICES ON 29 SHRIMP FARMS IN SOUTHERN HONDURAS.

Variable	Number of Farms	Mean (± SD)	Range
Feeding initiated (days after stock)			
all farms	29	15 ±12	1-45
feeding initiated at stocking	10	2 ± 1.3	1-5
initiation of feeding delayed	19	22 ± 9.9	14-45
Initial feed rate	22	11.7 ± 8.8	1-35
Final feed rate	22	2.4 ± 0.9	1-4
Feeding frequency (times/d)	29	2 ± 1	1-4
Maximum daily feed rate (kg/ha)	29	22.5 ± 8.0	4.5-36

On 10 farms (34 percent) feed is offered once daily, on 16 farms (55 percent) feed is offered twice daily, on two farms (7 percent) feed is offered three times daily, and on one farm (3 percent) feed is offered four times daily. Feed is distributed by boat over the pond surface on 27 farms (93 percent), distributed completely on feed trays (15 trays/ha) on one farm, and broadcast from the pond dike on one farm. The feed boat generally takes a zigzag route through the pond to ensure wide distribution of feed throughout the pond. On farms that feed once daily, distribution of feed begins about 0800 h and continues until completed. Depending on farm size, distribution of feed takes several hours to the entire day; these farms employ a minimum number of feed crews. Where feed is offered twice daily, generally the first feed distribution begins at 0700 h and the second distribution begins at 1300 h. If feed is offered more than twice daily, additional feedings generally occur during the late afternoon or evening hours. All farm managers maintain daily written records of feed applied to ponds. Managers report an average maximum daily feed ration of 22.5 ± 8.0 kg/ha. Twenty-one managers (72 percent) say they have no upper limit to daily feed ration. Eight managers (28 percent) report they will not exceed a mean daily feed ration of 35 ± 8.8 kg/ha (range: 27-45 kg/ha).

Twenty-seven managers (93 percent) know that feed conversion ratio (FCR) is calculated by dividing the total amount of feed offered by the total weight (wet) of whole shrimp harvested. Two managers rely on the farm technical director/consultant to make this calculation.

Most farms re-initiated production in early 1999 after total or near-total losses caused by Hurricane Mitch. Pond management strategies have changed on a number of farms as a result of the hurricane and the outbreak of WSSV. Managers report average FCR for their farm year to date to be 1.36 ± 0.49; FCR ranges from 0.09-2.43. Two managers do not know the FCR for their farm. Two other managers are just starting and do not yet have data available.
Because of the change in pond management strategy, many managers do not have a full year of data to provide current rainy and dry season FCRs, so managers report historic FCRs, generally from 1998. Fifteen farm managers report seasonal variation in FCR. Feed conversion ratio is lower during the rainy season, and averages 1.36 ± 0.30, compared to the dry season mean FCR of 1.60 ± 0.47. The range of FCRs is similar for rainy (0.77-2.00) and dry (0.50-2.25) seasons. Twenty-seven managers (93 percent) report no accumulations of feed on pond bottoms at harvest. One manager does not know whether

Honduran Industry Practice – Feed Management, cont.

or not accumulation of feed is observed on pond bottoms at harvest. On 14 farms the presence of feed in cast nets during population samples or weekly growth samples is one mechanism to detect uneaten feed on pond bottoms during the culture cycle. Data is unavailable for one farm in its first year of operation.

In response to the question about what feed rate causes problems with pond DO concentration, 26 managers (90 percent) report they have no such experience and are unable to state a specific feed rate. Two managers report that a feed rate of 45 kg/ha per day will cause problems with pond DO concentration. One manager reports that a feed rate in excess of 18 kg/ha per day in ponds without water exchange will cause unacceptably low pond DO concentrations.

Farm managers cite seven reasons for suspending feed application to a pond. Five managers (17 percent) suspend feed application for only one reason: low DO concentration, four managers, or disease. The remaining 83 percent of farm managers cite multiple reasons for stopping feed application to a pond. Low pond DO concentration and disease outbreak are the two most common reasons to suspend feeding. Feed application is suspended at a mean DO concentration of 2.2 mg/l.

On these farms, feed management appears to be good, as evidenced by feed conversion ratios that are in an acceptable range. Most farmers attempt to monitor shrimp growth, consumption of feed and FCR through some program of regular sampling. Farmers have also reduced the protein content of feeds in recent years. Feed is also offered on a frequent basis in a manner intended to promote good consumption, and feeding crews are monitored. The effects of feeding rates on water quality are also followed.

Although the importance of managing feeding appears to be recognized, not all farmers adhere to all recommended GMPs. Farmers also vary widely in their methods of monitoring and regulating feed and water quality. Further improvements may be possible if more regular and reliable methods of monitoring and regulation are adopted by a larger number of farmers. The change in management strategy towards enhancing returns rather than yields may motivate adoption and implementation in the future.

before 2.5 mg/l, and application of feed during these times is wasteful and may cause water quality problems. Wait until DO concentrations rise to at least 3 to 4 mg/l. If DO concentrations are chronically low, feeding rates are probably excessive for the assimilative capacity of the pond.

9.5 Fertilization and Phytoplankton Management

Fertilizers contain nutrients that promote phytoplankton growth. Phytoplankton is the first level of the pond food chain that culminates in shrimp flesh. Abundant natural productivity of phytoplankton reduces use of manufactured feed. The concentration and type of algae present in the water column has a direct effect on water quality.

Algae produce oxygen during the sunlit hours. They also help control ammonia concentrations by absorbing it from the water (Tucker et al. 1984). However, excessive concentrations of algae can result in low DO concentrations. Blooms of certain species of blue-green algae can be toxic to shrimp, or can produce odorous compounds that impart an off-flavor to shrimp making them unacceptable to consumers (Lovell and Broce 1985).

Chemical fertilizers should only be used when necessary to increase phytoplankton abundance.

This practice reduces unnecessary addition of nutrients to ponds, lowers costs and improves effluent quality. Pond water quality should be monitor with a Secchi disk to estimate light penetration in a pond. Optimal Secchi disk readings range from 25 to 40 cm. Readings greater than 40 cm indicate low algal levels and the need to increase nutrients with fertilizer. Secchi readings should never be allowed to fall below 25 cm, as this indicates overly dense algae populations. Where phytoplankton blooms are excessive, respiration by the phytoplankton community causes low DO concentrations during the night. Also, for a number of complex limnological reasons, dense algae populations can quickly die, causing high oxygen consumption from decay of the large algae biomass (Boyd et al. 1997; Barica 1975). This reduces oxygen for the shrimp and may cause mass mortalities.

Excessive applications of urea and ammonium fertilizers should be avoided.

Urea hydrolyzes to ammonia. If applications of urea to ponds are too high, the ammonia concentrations can be toxic to shrimp and to aquatic organisms in the receiving waters. Ammonia also has an oxygen demand and creates acidity in water when it is converted to nitrate by nitrifying bacteria (Mitchell 1992).

Liquid fertilizers are preferred, but if granular fertilizers are used, one of several methods should be used to ensure their dissolution.

When broadcast, granular fertilizers tend to settle to the bottom. Here the fertilizers dissolve and the phosphorus is quickly absorbed by the soil and does not enter the water column where it can be used by plants (Teichert-Coddington et al. 1997). Granular fertilizers can be applied on underwater platforms, dissolved in drums and the slurry applied to pond surfaces, or the fertilizer ration can be placed in a porous bag and hung in the water inlet.

If it becomes necessary to use organic fertilizers, the use of manures should be avoided unless their quality can be confirmed.

Organic fertilizers are less desirable for use in ponds than inorganic fertilizers because their nutrient content is highly variable and their decomposition may cause water quality problems. If the manager wants to use organic fertilizers, plant meals or other inexpensive plant products are preferable to animal manure. Plant meals are not as likely as manures to be contaminated with heavy metals and antibiotics. If manures are used, they should be first composted, making them better quality than the original manure. Obtaining manure from known sources helps confirm that it is free of contaminants.

It is common for pond managers to base fertilization schemes on pond color. Additional analysis, such as algae counts and indentification may also be necessary.

TABLE 3.
PREFERENCE FOR WATER COLOR OF SHRIMP POND AND PHYTOTPLANKTON GROUP REPORTED BY MANAGERS OF 29 SHRIMP FARMS IN SOUTHERN HONDURAS.

	Number of Farm Managers
Pond Water Color	
Green	1
Clear green	1
Emerald green	2
Seawater green	1
Olive green	1
Dark green	2
Yellow green	4
Brownish green	1
Yellow brown	8
Golden brown	3
Clear brown	2
Brown	2
Anything but strong greens	1
Phytoplankton	
Diatoms	21
No preference	7
Dislike of greens/blue-greens	1

Fertilizers should be stored in a clean, dry place away from sparks; spills should be avoided.

Some fertilizers, e.g., ammonium nitrate and sodium nitrate, are highly explosive and must not contact oil or electrical sparks. Moisture tends to cause fertilizers to form hard lumps. Fertilizer spills may pollute nearby water with nutrients.

9.6 WATER EXCHANGE AND FRESHWATER INPUT

Water exchange has historically been used in extensive shrimp culture to bring water with nutrients and shrimp food organisms into ponds, to prevent high salinity in the dry season and to supply oxygen. The practice was continued in semi-intensive and intensive shrimp farming because it was thought that nutrients, ammonia, and phytoplankton would be flushed from ponds to improve water quality. In some areas, a degree of water exchange is needed to prevent high salinity in the dry season. However, water exchange as a method to manage water quality is now thought to be questionable in most situations. Water exchange flushes nutrients and natural productivity from semi-intensive ponds; it is not clear whether supposed benefits outweigh this loss. Water exchange also greatly increases effluent volume. Many farmers now regard water exchange as a risky practice because contaminants, disease or pest organisms may be introduced to the ponds in this manner.

In intensive ponds, and to some degree in semi-intensive ponds, water quality deterioration may result from excessive stocking and feeding rates. Some water quali-

Honduras Industry Practices – Fertilization

Twenty-five farm managers own and use a Secchi disk, while four managers either do not have or do not use a Secchi disk. Only two farms purchased a Secchi disk, while on 23 farms the disk was fabricated on-farm. A Secchi disk diameter is 20 cm (10 farms), 25 cm (8 farms), 30 cm (5 farms) and 40 cm (1 farm). While Secchi disk measurements are used to guide pond fertilization decisions on 17 farms, aSecchi disk measurements are made routinely on 25 farms. Farms have an average of 2.3 people (range: 1to 6 people) responsible for SDV measurements. A Secchi disk visibility is measured by a standardized method on all farms; however, methodology varies slightly farm to farm. Most variation is in the time SDV is measured. Recommended technique is to measure SDV between 1100 and 1300 hours when the sun is directly overhead. Measurements on farms take from 30 minutes to 2 hours. Ten farms (40 percent of farms that use a Secchi disk) begin SDV measurements at 1100 or 1200 hours. Secchi disk visibility is measured beginning at 0600 hours on one farm, 0800 hours on one farm, 0900 hours on three farms, 1000 hours on five farms, 1300 hours on three farms, 1400 hours on one farm, and 1500 hours on one farm. On 19 farms, SDV is measured only at the pond outlet structure. Measurements are taken at the inlet and outlet structures on four farms, from a boat in the middle of each pond on another farm, and always from an upwind position on one farm. Frequency of SDV measurement ranges from daily to weekly.

While three farm managers report that ammonia concentrations in pond waters are measured weekly, not one manager reports monitoring pond water nitrogen or phosphorus concentrations to guide pond fertilization decisions. In fact, no farm manager reports fertilizing ponds to maintain a specific concentration of nitrogen or phosphorus in pond waters.

Managers on 20 of 21 farms using fertilizers exchange water in ponds that have been fertilized only in response to specific criteria, e.g., low DO concentrations, or after a delay of 1.5 to 7 days. Only four of these managers reduce water exchange rates by 25 to 50 percent in ponds fertilized recently, and only up to four days after water exchange resumes.

Pond phytoplankton populations also are monitored through visual observation of pond water color and by phytoplankton counts. Water color is recorded daily on 10 farms. Plankton counts are made on five farms, usually at 7 to10-day intervals. Manager preferences for pond water color are varied, and range from seawater green to emerald green to yellow/golden-brown to anything but strong greens (Table 3). The three most preferred water colors are, in descending order, yellow-brown, yellow-green and golden brown (Table 3). Farm managers express a preference for only one type of phytoplankton; diatoms. Twenty-one managers (72 percent) prefer pond phytoplankton populations be composed primarily of diatoms (Table 3). Seven managers have no preference for a predominant phytoplankton group. One manager states a dislike for green and blue-green algae, rather than a preference.

ty problems may also exist in local water sources. These can exacerbate water quality management problems such as high sediment loads, low productivity or contamination. Thus, poor water quality in ponds can often be improved more efficiently by resorting to reasonable stocking and feeding rates than by exchanging large volumes of water. Water exchange is an expensive practice because it increases the amount of water that

Applied Research for Reducing Use of Fertilizer in Honduran Shrimp Ponds

Benefits

Fertilizers are used in aquaculture as a means of providing nutrients for phytoplankton and, indirectly, for zooplankton. These organisms are consumed by shrimp and can provide a significant source of food, thus reducing the need to add formulated feeds in semi-intensive shrimp farming. The ability to reduce fertilization rates without affecting production lowers production costs and may improve effluent water quality under certain circumstances.

Complexities

The need for fertilizers is dependent on many factors that are inter-related in complex ways. These factors include water and soil quality, temperature, concentrations of nutrients in local waters, and local phytoplankton population characteristics. All of these vary greatly between farms, even between individual ponds. It is important not to reduce fertilization too much, since this could affect natural productivity and increase the need for formulated feeds.

Current Status of Research

Shrimp ponds in Honduras are classified as embayment or riverine types, with reference to their location on the Gulf of Honduras or on riverine estuaries. Riverine farms receive more exogenous nutrients in runoff from surrounding watersheds (Corrales et al. 1998). Research was conducted by Auburn University PD/A CRSP in Honduras to investigate the optimal level of fertilization for the two types of farms.

Results indicate that fertilizer could be reduced or eliminated for the riverine-type farm where waters were already nutrient rich. In comparison, farms located on the embayments of the Gulf of Fonseca have source water that is very low in nutrients, in which case fertilization can be beneficial. Furthermore, this study was conducted at a time when water exchange rates were relatively high, which meant that fertilizer nutrients were being washed out of ponds each water exchange. Thus, the results indicate that fertilization can be reduced or eliminated, or applied only at farms that have a water source high in nutrients (e.g., riverine farms).

Water exchange rates have been reduced dramatically on many farms in Honduras. There is a renewed interest in fertilization of ponds on an "as needed" basis at those farms subject to low rates of water exchange. In these situations, fertilization may be beneficial since applied nutrients are retained in the pond to stimulate natural productivity which, in turn, can act to spare feed inputs (Green and Teichert-Coddington 1990; Rodriguez et al. 1991).

must be pumped. Nutrients and organic matter are flushed out before they can be assimilated by ponds, possibly resulting in eutrophication of receiving waters. Also, greater water movement within ponds and canals leads to more suspended solids in effluents causing sedimentation in coastal waters.

Consideration should be given to whether water exchange will improve pond water quality, or whether other steps should be taken.

Routine water exchange is probably of little benefit unless it improves water quality in ponds. Often other methods may be more effective in addressing water quality problems. Water exchange may be necessary in some cases such as reducing high salinities in the dry season (Boyd 1997a). Salinity usually can be controlled with a water exchange rate of 2 to 3 percent of pond volume per day.

Do not mix freshwater from wells with pond water to control salinity.

Shrimp can be cultured over a wide range of salinities (Ponce-Palafox et al. 1997); thus, there is

Honduras Industry Practice – Fertilization, Cont.

Twenty-six (90 percent) of farm managers report that they like to have a phytoplankton bloom established in the pond before shrimp are stocked. Stimulating the plankton bloom may or may not involve application of chemical fertilizers. Fertilizers may be added during only the dry season, when many mangers feel that source water is less fertile. Managers feel that source-water fertility during the rainy season is high enough to obviate the need for fertilizer applications on many farms, especially those located on riverine estuaries. No farm uses chicken litter or chicken manure as a pond fertilizer. In fact, only one farm uses any kind of organic fertilizer at all: 22.7 kg/ha of dried cattle manure are applied to the pond bottom prior to pond inundation.

Ponds are fertilized on 21 farms (72 percent). However, one manager has stopped fertilizing ponds since a WSSV outbreak occurred in early 1999 and has no plans to continue pond fertilization. Two managers report using minimal quantities of fertilizer because source water had sufficient nutrient content. Four managers report fertilizing ponds only during the dry season when they report source-water nutrient concentrations are lower. Four fertilizers are used by farm managers: urea (46-0-0; granular) fertilizer is used on 20 farms (69 percent), diammonium phosphate (DAP; 18-46-0; granular) fertilizer is used on 17 farms (59 percent), triple superphosphate (TSP; 0-46-0; granular) is used on three farms (10 percent) and ammonium nitrate (34-0-0; granular) is used on one farm. Urea and ammonium nitrate are used as a source of nitrogen, while DAP and TSP are used as a source of phosphorus, although DAP also contains nitrogen. Urea and DAP are the most common fertilizer sources of nitrogen and phosphorus, respectively. On all farms that fertilize, the primary objective is to establish stable plankton blooms. Shrimp feed on the resultant natural productivity. This allows provision of commercial rations to be delayed until rapid shrimp growth no longer is supported by natural productivity, or to be offered at lower rates. Two farm managers report that, in addition, they fertilize to promote diatom blooms. On 15 of 21 farms that fertilize, fertilizer to be applied is pre-dissolved and the fertilizer solution distributed throughout the pond from a boat. On one farm, fertilizer is placed in a porous bag suspended in the pond inlet and is dissolved and distributed into the pond by influent water. Fertilizer is applied on five farms (23 percent) by broadcasting over the pond surface. Fertilizer is stored on skids in a storage building on 18 farms, on the floor of the storage building on two farms, and purchased as needed on one farm.

Fertilizer application rates vary considerably among farms. Mean fertilizer N:P ratio is 27.2:1 and 27.5:1 for the initial and normal fertilization rates, respectively. The N:P ratio decreases to 21.5:1 on those farms that use a third fertilization rate. Seventeen farm managers (59 percent) report that the need for pond fertilization is determined by Secchi disk visibility. Fertilization is used to maintain Secchi disk visibility (SDV) in the range of 30 to 40 cm. Managers on four farms apply fertilizers on a routine basis, usually weekly. On 16 of 21 farms (76 percent of farms that fertilize) using fertilizers, there is an initial fertilization rate that is higher than subsequent fertilization rates and is applied while the pond is filling or prior to stocking the shrimp. A second (normal) fertilization rate is used when SDV exceeds the 30 to 40-cm target depth; additional rates, intermediate to the initial and normal rates, may be used if SDV greatly exceeds the target depth. Managers on six farms use only one fertilization rate based on SDV, while managers on 11 farms use fertilization rates that vary with SDV. Two farm managers use plankton counts as one factor, and one manager also uses pond color as another factor in the decision to fertilize. Two farm managers practice routine fertilization at a fixed rate.

Honduras Industry Practice – Fertilization, Cont.

Fertilization rate does not vary between rainy and dry seasons on 14 of 21 farms that fertilize. However, on seven farms, fertilization rates do vary seasonally. During the rainy season, five farms do not fertilize at all, and two farms reduce fertilization rates by 50 to 80 percent because managers report increased nutrient content of source water. Fertilizer N:P ratios do not vary seasonally.

Fertilization practices on Honduran farms vary, but most farms do monitor using a Secchi disk, and attempt to fertilize in response to the desired phytoplankton bloom. The means of judging phytoplankton type by visual observation is not necessarily reliable, and a wide range of preferences are expressed for pond color. Attempts to establish a suitable phytoplankton bloom prior to stocking, and maintain it afterwards, are made through reduced water exchange. Most farms do not test for levels of nitrogen and phosphate, and many do not vary fertilization rates properly according to the changing water nutrient levels during the wet and dry season. Most farms can improve on at least some fertilization practices. And this can be encouraged through providing technical information on the full range of desirable practices.

generally no need to dilute saltwater with freshwater. Extracting freshwater from wells may cause land subsidence and saltwater intrusion into aquifers or surrounding agricultural lands (Liao 1986; Primavera 1993). Additionally, freshwater for domestic use is increasingly becoming a scarce resource in many parts of the world, thus unnecessary use should be avoided.

Reuse water where practical.

Some of the newer farm management techniques involve cycling water through a system of ponds that allow the water to be depurated and reused. Aside from reducing effluent loads, this practice is advantageous because it reduces inputs from the external ecosystem, thus helping to lower risk of predator intrusion, spread of disease from other farms or wild shrimp, and loss of natural productivity from within the farm ecosystem.

9.7 Dissolved Oxygen Management

Dissolved oxygen is the most important of all water quality factors to good shrimp production. Adherence to a good feeding and fertilization regime coupled with regular water quality monitoring is the first step in maintaining adequate DO concentrations (above 3 to 4 mg/l). However, mechanical aeration is necessary in intensive shrimp farming. Aeration is not common but has been used in some areas of Latin America, thus general GMPs are offered. Mechanical aerators should be used with care because they are costly to purchase, operate and maintain. Aerators may also cause erosion of pond bottoms and embankments and increase contaminant loads in effluents (Boyd 1997b).

Mechanical aeration needs to be estimated so excessive aeration is avoided.

Excessive aeration wastes energy and causes erosion. One horsepower of aeration will normally allow an additional 400 to 500 kg/ha of shrimp production above that possible without aeration (Boyd 1997b).

Aerators with good oxygen-transfer efficiency should be used.
Using efficient aerators reduces the number of aerators needed and reduces operation and maintenance costs. Large aerators (2 horse power or larger) are preferred because they cause less erosion per unit of power than do smaller aerators.
Most erosion occurs immediately in front of aerators. One large aerator will cause erosion in fewer places than will several small aerators.

Aeration appropriate to the biomass of shrimp in the pond should be used during the crop production cycle.
Heavy aeration when not needed wastes energy and increases erosion. The need for aeration can be determined through regular water quality monitoring.

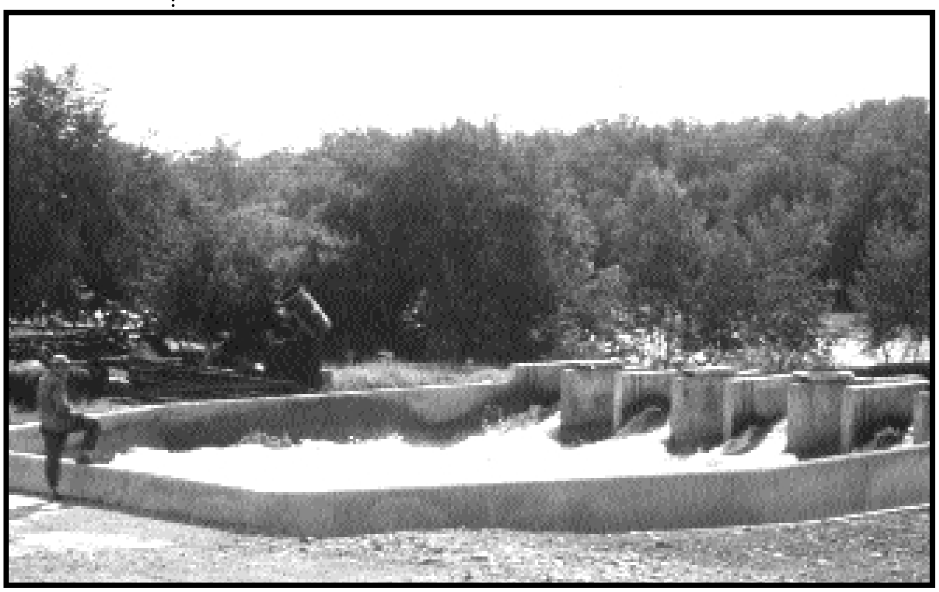
Where ponds have multiple aerators, fewer aerators should be operated in daytime than at night.
During the day, oxygen production by algae will raise DO concentrations naturally, thus less aeration is needed.

Aerators should be positioned at least 3 to 4 m from embankment toes to reduce erosion.
Erosion can also be minimized by reinforcing bottom areas in front of aerators by compaction or with stone riprap. Aeration effects should be monitored, and if erosion is observed, reposition aerator to reduce water velocities at critical places.

The simplest aeration systems should be used and properly maintained.
Surface paddlewheel aerators or propeller-aspirator-pump aerators are efficient and are the easiest to install and maintain (Boyd and Ahmad 1987; Ahmad and Boyd 1988). Good maintenance is important because aerator failure can cause mass shrimp mortality.

9.8 Liming

Liming is done to increase the pH and alkalinity of water and to increase the pH of acidic soils. Many soils are naturally acidic because they have low concentrations of basic ions or large amounts of organic matter. Potential acid-sulfate soils become highly acidic when dried because iron pyrite contained in them is oxidized to sulfuric acid (Boyd 1995a). Liming is known to be highly effective in neutralizing soil acidity; it can be a useful and inexpensive management tool. Farmers tend to use more lime than necessary, but over liming is normally not harmful to ponds and seldom causes



Pumping to exchange water is one of the major operational costs of shrimp farming. Significant reductions in water exchange may be possible without loss of production.

Applied Research on the Effects of Reducing Water Exchange Rates in Semi-Intensive Culture in Relation to Yields

Benefits

Water exchange is practiced on shrimp ponds with the belief that it improves water quality by removing wastes, increasing DO concentrations and maintaining the desired salinity. In Central America, farm management practices rely on water exchange because mechanical aeration is rarely used (Teichert-Coddington 1995). There is some doubt about the effectiveness of using water exchange as a water quality management tool. Research is needed to determine if this is beneficial, because there are known costs of water exchange such as fuel costs, maintenance requirements, contributions to sedimentation of canals and ponds and the possibility of increasing total nutrient discharge from ponds.

Complexities

The effects of water exchange on pond water quality parameters are poorly known. Additionally, these parameters are also affected by a host of other factors which may complicate experiments. There are also seasonal effects, differences in water quality according to source, and differing farm management practices that will affect the efficacy of using water exchange to manage water quality.

Current Status of Research

Two water exchange regimes were tested in ponds stocked with *P. vannamei* in Choluteca, Honduras, during the wet and dry season. Water exchange was either performed daily (10 percent of pond volume) or only in response to very low DO concentrations (<2.0 mg/l). Water quality variables were monitored.

Gross shrimp yield, average size, and survival rate did not differ significantly under either water exchange regime despite some differences in water quality variables. Water exchange appeared to have more effect on water quality during the rainy season.

While the researchers were unable to conclude that no benefit was offered by water exchange, the results do indicate that lowering water exchange rates significantly is possible without affecting important production variables. It is suggested that minimally, water exchange can be delayed until week 10 of the production cycle (Green et al. 1998).

Water Exchange

Water is exchanged in production ponds on a daily basis on 14 farms (48 percent) or in response to manager-determined criteria on 15 farms (52 percent). Daily exchange is estimated by managers to be 5 to 15 percent of pond volume, and depends on pumping capacity, reservoir capacity and number of ponds with DO crises. Secchi disk visibility (SDV) and DO concentration are the two most common criteria used either alone or in combination to make the decision to exchange water. Among criteria used by farm managers in their decision to exchange water: two managers base their decision solely on pond DO concentration, three on pond SDV, six on both DO concentration and SDV, one on DO concentration and water color, one on SDV and water color, one on algal counts, and one on shrimp size. Most decisions to exchange water were based on DO concentration. These used a minimum DO concentration (3.0 to 3.5 mg/l) to trigger water exchange. On a couple of farms a maximum afternoon DO concentration greater than 17 to 18 mg/l provokes a decision to exchange water; one manager will exchange water if the afternoon DO concentration is 4 to 5 mg/l. Where SDV is used to make a decision to exchange water, the critical SDV is less than 25 to 35 cm. The two managers who use water color in their decision, exchange water if the pond is bright green. The farm manager who bases the decision to exchange water on algal counts increases water exchange rate with increased algal counts.

Applied Research on the Effects of Reducing Water Exchange Rates in Semi-Intensive Culture in Relation to Yields, Cont.

Research conducted under Honduran conditions indicates that routine water exchange may not be necessary. In spite of this, about half the farms routinely exchange water on a daily basis, a practice that has certain economic costs, and may possibly produce environmental impacts. In the case of farmers who do use some criteria to trigger water exchange, the criteria vary widely. Improvements in this area could be made if more farmers were to consider using water quality criteria as the basis for water exchange, rather than routinely exchanging water. Use of a critical DO as a criteria is a good practice in this case; most farms already measured DO levels regularly (24 of 29 farm).

excessive pH in effluents.

Agricultural limestone, rather than burnt lime or hydrated lime, should be used for neutralizing soil acidity.
Agricultural lime does not cause high pH like burnt lime or hydrated lime (Boyd and Masuda 1994). Burnt lime and hydrated lime should be used on pond bottoms when necessary to disrupt pathogen cycles.

Waters with total alkalinities above 50 to 60 mg/l should not be limed.
Liming waters with high alkalinity is ineffective because the lime will not dissolve in this water (Boyd and Masuda 1994). Usually it will only be necessary to lime between crops.

Liming materials should be applied uniformly over the pond bottom surface, and tilling to a depth of 5 to 10 cm will speed reaction of liming material.
Lime must come into direct contact with all parts of the pond bottom to be effective. Tilling helps spread and mix the lime into the soil more rapidly than would occur naturally.

Liming materials should be applied on the basis of soil testing.
Soil samples should be collected from at least 10 equidistant sites along an S-shaped pattern from the shallow to deep ends of the pond; the samples are combined and a sub-sample withdrawn for analysis (Boyd and Tucker 1992).

9.9 Health Management

There is much that is unknown about shrimp diseases, their causes, and treatment. Newly introduced diseases have played a role in the epidemics that have swept through shrimp farming areas throughout the world. It is known that the onset of disease usually follows periods of stress. A general tenet in aquaculture is that onset of epidemic disease often may be attributed to poor management practices which weaken the resistance of culture animals. The reason for the virulence of recent shrimp epidemics is not clear. The precau-

HONDURAN INDUSTRY PRACTICES – DISSOLVED OXYGEN MANAGEMENT

Dissolved oxygen (DO) is measured in ponds on 27 of the 29 farms. On three farms, DO is measured either every two days, once weekly, or whenever the manager feels there is a problem. On the remaining farms, DO is measured from two to six times daily, for an average of three times daily. On average, DO is measured one time during daylight hours, most often between 1400 to 1600 h, and two times during the night, most often between 2400 to 0600 h. Actual DO measurement times vary from farm to farm. DO measurements are made at one site in the pond, most often at the outlet structure. Where DO is measured twice in a pond, it is at the inlet and outlet structures. Mean sample depth for DO measurements is 68 cm below the surface. On four farms DO is measured at two depths; one near the surface and the other just off the bottom.

Five actions are taken in response to low pond DO concentration. Two farm managers (7 percent) have only one response to low pond DO concentration: increased water exchange. The remaining farm managers cite multiple responses to a pond DO crisis. Increased water exchange is the first response implemented by managers on all 29 farms. Suspension of the feed ration (day or morning) occurs on 26 farms if pond DO concentration is less than 1.0 to 2.5 mgl. Daily feed rate is reduced by 50 percent on seven farms if pond DO concentration is 1.0 to 3.0 mg/l. Emergency aerators (tractor PTO-powered paddlewheel aerators) are deployed on eight farms, and motor boats are used to aerate pond water on 12 farms.

DO is routinely and closely monitored on farms. With the possible exception of more consistent measurements in the case of some farms, farmers generally practice the recommended GMPs in this area.

tions are to prevent stressful culture conditions and prevent the introduction of new disease.

Diseases are thought to be introduced through imported shrimp (adults and PL), by birds and possibly by humans traveling between farms. Stress may come from chronic water quality problems such as repeatedly low DO levels, high un-ionized ammonia concentrations, crowding, temperature extremes during transport or handling, or poor diet.

Three primary diseases have been detected on farms during the past 12 months (Table 5). Taura Syndrome Virus (TSV) and White Spot Syndrome Virus (WSSV) are the two most common viral diseases reported, while vibriosis is the most common bacterial disease reported. Managers of two farms reported detecting no diseases on farm during the past year.

When possible, PL should be purchased that are disease free and come from reputable hatcheries.

Specific pathogen free or resistant (SPF or SPR) PL are available from some hatcheries. These strains may be an option, although they have not always performed well. Even though cautions have been taken to assure that the hatchery is properly operated, there have been outbreaks of disease in these SPF-certified hatcheries. PL can be held in quarantine tanks or ponds after shipment from a hatchery if there is any doubt about their health, but this also may not screen out all infected animals. Sinderman (1988) gives some guidelines for quarantine of marine animals.

Good water quality should be maintained in the ponds.

Following the guidelines on pond management given in this paper greatly improves the probability of maintaining healthy growing conditions for shrimp. Refer to GMPs in sections 9.4, 9.5 and 9.14.

Causes of mortality should be identified.

If shrimp begin to die, they should be analyzed by farm laboratories, or if necessary, in a certified pathology laboratory. Identifica-tion of the cause of disease may help identify its sources and may allow preventive measures to be taken. Without such a diagnosis, there is little a farmer can effectively do.

TABLE 4.

STATED OBJECTIVES FOR LIME USE ON FARM OR FOR APPLICATION TO FULL PONDS ON 29 SHRIMP FARMS IN SOUTHERN HONDURAS. TWENTY-FIVE FARM MANAGERS REPORT USE OF LIME ON FARM, AND 22 MANAGERS REPORT LIME APPLICATION TO FULL PONDS. MANY MANAGERS REPORT MULTIPLE OBJECTIVES TO LIMING.

Objective	Number of Managers Reporting	
	Use on Farm	Applications to Full Ponds
Increase soil pH	4	-
Adjust water pH	4	-
Regulate phytoplankton population	7	8
Sterilize pond bottom	20	-
"Improve" shrimp texture	5	5
Control bacteria in water	2	14
Correct off-flavor	1	4
Treat puddles and drain canal before filling	1	-

If an effective disease treatment is available, it should be used promptly and properly to limit disease.

There are many pharmaceuticals, natural remedies and other chemicals being sold to prevent or cure disease. Some of these are ineffective or are only effective for certain diseases. Some drugs, such as antibiotics, may be harmful if used improperly. Inappropriate use of chemical products is costly, some products can contaminate the environment, and residues of some medicines that accumulate in shrimp can pose a health hazard to the consumer. Cautious and conservative use of chemotherapeutics, including antibiotics, is necessary. Technical expertise should be sought if chemicals are to be used.

Technical information on the use of chemotherapeutics should be developed for regional industries.

The shrimp farming industry needs to prepare an approved list of chemicals, chemical uses, and instructions for use of approved chemicals such as has been done in the United States (Federal Joint Subcommittee on Aquaculture 1994). Explicit dosages are needed for each approved chemical.

Water should not be exchanged in ponds with disease problems, particularly if it is suspected that a new disease organism may be involved.

Exchanging water within the ponds of an operation or to outside receiving waters will spread disease. In areas where disease is a problem, limiting or eliminating water intake is a good idea since there is less chance that disease will be spread from neighboring farms. Recycling water will reduce the incidence of disease outbreaks by minimizing the opportunity for introduction of water-borne pathogens into the facility.

Honduran Industry Practices – Liming

Farm managers were asked about lime usage twice during the interview: once in the context of general usage and once in the context of liming as a water treatment. Twenty-five farm managers report using lime on the farm. Eleven managers cite only one reason for on-farm lime uses, while 14 managers cite multiple reasons (64 percent cite two objectives and 36 percent cite three objectives).

Of the eight reasons given by managers for using lime on the farm, pond-bottom sterilization is cited by 20 of 25 managers, while phytoplankton control is cited by seven of 25 managers.

In pond-bottom sterilization, hydrated lime is broadcast over the pond bottom after pond draining. Twenty-two farm managers report applying lime to pond water during the culture cycle. Fourteen managers give only one reason, and eight managers give multiple objectives (88 percent cite two objectives and 13 percent cite three objectives) for applying lime to water during the culture cycle. The two most common reasons reported for adding lime to full ponds are control of bacteria (12 farm managers) and control of phytoplankton populations (eight farm managers). Hydrated lime [$Ca(OH)_2$] is applied on 21 farms, and quick lime (CaO) is applied on one farm. Lime applied to full ponds is applied as a slurry of lime mixed with pond water. Application rates of lime vary considerably among farms, and sometimes within a farm depending on the objective.

Most farmers cite pond-bottom sterilization as the primary objective in liming. This may be one of the few preventive measures available for prevention of disease. In spite of the perceived and real importance of this practice, lime application is only 40 percent of the recommended treatment rate, and application is patchy throughout the ponds. This practice could be improved.

Ponds that have had serious disease mortality should not be drained until disease organisms have been deactivated by chlorination or other means.

If pond waters are to be disinfected, biodegradable chemicals should be used. An adequate period of detoxification should be allowed before these waters are released or reused.

Dead and diseased animals should be disposed of in a sanitary manner.

Dead and diseased animals should be treated with quick lime and buried, or some other suitable method should be used.

Entry of wild animals and escape of domestic animals should be minimized by screening intakes or by other suitable methods.

While the potential to spread diseases in this manner has not been thoroughly documented, isolation of ponds is a good preventative method.

Bottoms of diseased ponds should be dried for two or three weeks and treated with 1 to 2 tons/ha of burnt lime to raise the pH and to disinfect the pond.

Treatment with burnt lime or hydrated lime at 1,000 to 2,000 kg/ha will kill disease organisms and their carriers (Boyd 1995a). Lime should be applied uniformly to the entire pond bottom.

Cooperate and communicate with neighboring shrimp farmers regarding disease problems to minimize the spread of disease.

Good practices, when adopted by the neighboring farmers, will help prevent and combat diseases.

9.10 Chemical and Biological Agents

A large number of chemicals are used in aquaculture, but only a few have beneficial effects. Most serious shrimp diseases are viral in nature, and these cannot be treated with common chemotherapeutics (Hopkins et al. 1995b). Many chemicals promoted for aquaculture are ineffective or harmful, either to shrimp, workers, the environment, or consumers. Some chemicals can cause adverse effects such as toxicity or bioaccumulation by biota in receiving waters. Careful use of chemicals is necessary to lower costs and to prevent harmful effects. Approved lists of chemicals and chemical uses should be developed by government regulators and producers to guide use of these products.

Pesticides should be used appropriately.

Avoid general use of pesticides in ponds; they are toxic both inside and outside of ponds. Some exceptions are biodegradable compounds such as the insecticide Sevin, whose use can be strictly controlled. Water from treated ponds should not be used until these compounds have had enough time to biodegrade.

The use of antibiotics and other anti-bacterial agents should be limited to occasions when the presence of a pathogen susceptible to the agent is suspected.

These compounds can cause adverse environmental effects when discharged in effluents. Additionally, antibiotic resistant strains of pathogenic bacteria harmful to shrimp and humans might be created by overuse of antibiotics (Csavas 1990). There is also the danger of residues of these compounds in marketable shrimp. As with all of these products, compliance with the approved withdrawal period is mandatory to ensure food safety.

9.11 Pond Bottom and Sediment Management

Shrimp spend most of their time on the pond bottom, thus it is essential to the health of the shrimp that bottom soils be maintained in good condition at all times. A major problem is the accumulation of soft sediment, both from off-site and on-site sources (Boyd 1995a). Some GMPs for reducing erosion and sediment accumulation have already been listed. The following are additional aspects of bottom soil and sediment management.

When ponds are dried after harvesting, accumulated sediment should be moved back into areas where erosion has occurred.

This practice maintains the integrity of the pond bottom by leveling the surface. A level or slightly sloped bottom drains more rapidly and prevents puddles where predators and disease organisms can survive. The pond bottom does not need to be compacted unless aeration is to be used, in which case it is essential.

Sediment should only be removed from ponds when absolutely necessary.

Sediments will usually not accumulate unless there is a problem with heavy suspended solids in the intake water or if severe overfeeding and over-fertilizing is occurring. For the former, a sediment basin may be used to remove sediment. In the latter case, a complete revision of the feeding and fertilizing regime is needed. In some cases, farmers remove soil in areas where anaerobic processes have resulted in foul and toxic soil

When properly applied, lime should cover the bottom of the pond. An inadequate amount has been applied to the pond above.

If bottom soils are tilled between crops in ponds where mechanical aeration is used, pond bottoms should be compacted before refilling.
Compaction helps to reduce erosion caused by mechanical aeration during the production cycle.

If sediment must be removed from ponds or sediment basins, it should be disposed of in an environmentally responsible manner.
Do not put sediment in freshwater areas because it has a high salt burden. Salt may leach from saline soil and contaminate freshwater areas or lands.

accumulation. This should be solved by better water and soil management as outlined in the GMPs, rather than removing the soil as there are few good disposal areas for this soil.

If pH of bottom soil is less than 7, agricultural limestone should be applied between crops.
Organic matter decomposes most rapidly at pH 7 to 8; this is facilitated by the application of lime.

Bottoms should be allowed to dry for 2 to 3 weeks at minimum, at intervals of every 3 to 4 crops, and during the dry season.
Drying enhances aeration of the soil and stimulates decomposition of organic matter. Drying of pond bottoms can be done after every crop or a longer intervals if desired. However, long and frequent drying is not always necessary.

9.12 Predator Control

Predators can cause high economic losses. Where possible, the most environmentally friendly and effective methods to discourage predators should be chosen.

Inlet and outlet gates to ponds should be screened.
This practice can prevent wild animals, such as fish, from entering the ponds. It also prevents escape of domestic shrimp.

Ponds should not be located too close to mangroves because crabs and other animals will enter ponds.
In addition to preying on shrimp, some organisms may also carry diseases or compete with the shrimp for food.

Predation by birds should be minimized by non-lethal methods if possible.
Non-lethal methods include use of netting, noise-mak-

Table 5.
Use of lime, HTH (granular chlorine), and drying as treatments for full or dry ponds on 29 shrimp farms in southern Honduras.

Treatment	Number of Farms	Application Rate (kg/ha) Mean	Application Rate (kg/ha) Range	Objective/Comments
Pond Water				
Hydrated lime ($Ca(OH)_2$)	21	59	4.5-454	Bacteria and phytoplankton control most common objectives Applied as slurry
Calcium oxide (CaO)	1	34	23-45	Phytoplankton and off-flavor control
Pond Bottom				
Hydrated lime	20	395	45-1,089	Disinfect pond bottom Broadcast application
Calcium carbonate ($CaCO_3$)	1	396	No data available	Adjust soil pH - not used in 2 years
HTH (granular chlorine)	13	variable	No data available	Poison puddles on pond bottom
Drying	17	No data available	No data available	Primarily during dry season

Table 6.
Shrimp diseases detected as reported by farm managers on 29 shrimp farms in southern Honduras during 1998-1999.

Disease	Number of Farms Reporting	(percent of total)
Taura Syndrome Virus (TSV)	27	(93)
White Spot Syndrome Virus (WSSV)	20	(70)
Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV)	13	(45)
Necrotizing Hepatopancreatitis (NHP)	15	(52)
Baculovirus (BP)	8	(28)
Vibriosis (V)	24	(83)

ing apparatus or hiring laborers to scare birds away.

9.13 Effluent Management

One of the greatest potential environmental impacts during operation of a shrimp farm is the release of pond water carrying a high nutrient load that produces hypernutrification or eutrophication of the receiving water (Hopkins et al. 1995a). The composition of pond effluent is a direct reflection of pond management practices, particularly feeding and fertilizing regimes. Pond effluents are not as concentrated in pol-

HONDURAN INDUSTRY PRACTICES – HEALTH MANAGEMENT

A variety of health management practices are implemented on the surveyed farms (Table 6).

Fourteen (48 percent) farms currently are having PL analyzed for WSSV by PCR test. Generally, these farms require that PL suppliers, especially from outside Honduras, provide PCR results for shipments of PL from their hatcheries.

In addition to the above PCR/dot-blot tests and field/laboratory exams, PL are subjected to a stress test prior to stocking on about half (52 percent) of the farms surveyed. Stress tests often were performed at local hatcheries or acclimation centers off-farm, before PL were transported to the farm for stocking. A sudden decrease from ambient salinity to freshwater (0 ppt) for a period of 15 to 30 minutes before salinity is returned to ambient salinity (nine farms), and being dipped into a formalin (100 mg/l) solution for 30 minutes (three farms) are the two most common stress tests. Either samples of PL or the entire population of PL are subjected to the stress test. Subjecting a sample of PL to crowding for 24 hours or a sudden increase in water temperature from 22 to 28 degrees C were the other two stress tests reported. Stocking of PL into production ponds on all farms takes place at the coolest time of day, i.e., pre-dawn hours. The acclimation process involves adjusting slowly the salinity and temperature of transport water to those of the production pond. The acclimation process is monitored closely by technicians to ensure that PL do not become stressed and that DO concentrations remain high at all times.

Farms also periodically evaluate shrimp using PCR when shrimp are suspected of being infected by WSSV. However, these samples must be sent to laboratories in Tegucigalpa or the United States. It is expected that the frequency of PCR analysis for WSSV will increase when ANDAH installs its PCR equipment in its shrimp pathology laboratory in Choluteca. Sixteen (55 percent) farms use the dot-blot test for WSSV; three of these farms first run the spot-on test, running the dot-blot for WSSV and infectious hypodermal and hematopoietic necrosis virus (IHHNV) only after a positive spot-on result. The remaining 13 farms do not use dot-blot for WSSV. Only five (17 percent) farms use dot-blot to diagnose Taura Syndrome Virus. Thirteen (45 percent) farms also diagnose IHHNV using the dot-blot test. Nearly all (90 percent) farms conduct some sort of evaluation of shrimp health at least weekly. This evaluation can involve macroscopic field exams for gross symptoms of any of the diseases, to weekly histopathological laboratory exams conducted by a microbiologist. Farms often combine field and lab evaluations in their shrimp health management plan.

Two sites in Honduras currently are capable of performing the PCR test: the National Automonous University of Honduras and a private diagnostic laboratory, both are located in Tegucigalpa. Some farms also send samples for PCR analysis to the United States. The ANDAH Aquatic Pathology Laboratory, located in Choluteca, is in the process of installing its own PCR equipment, and should be ready to begin performing analyses by the end of September 1999. Given its central location to the shrimp industry, once this equipment is installed, high demand for PCR analysis for WSSV is expected at the ANDAH Aquatic Pathology Laboratory.

Table 7.
Shrimp health management practices implemented on 29 shrimp farms located in southern Honduras.

Shrimp Health Management Practice	No. of Farms Implemented	No. of Farms Not Implemented	Comments
PCR test for WSSV	14	15	Required from international PL suppliers In-country analysis expected to increase when PCR equipment installed in ANDAH shrimp pathology lab
Dot-blot test for WSSV	16	13	Three farms perform dot-blot test only after positive response to spot-on test
Dot-blot test for TSV	5	24	
Dot-blot test for IHHNV	13	16	Three farms perform dot-blot test only after positive response to spot-on test
Bacteriology/histology/ parasite evaluation	26	3	Combination of field and laboratory exams Field exams can be as frequent as daily Lab exams generally conducted weekly
Stress test for PL	15	14	See text for description
Acclimate PL prior to stocking	29	0	See text for description

Honduran Industry Practices – Health Management, Cont.

Twelve farm managers, including the two who report no diseases, state they do not treat diseases. The remaining 17 farm managers do treat diseases. Medicated feed, either containing oxytetracycline (OTC) or Sarafin, is manufactured by a Honduran feed mill and is used on 12 farms (41 percent) to treat bacterial diseases. Oxytetracycline is given as a 14-day treatment and is used by farmers primarily to treat necrotizing hepatopancreatitis (NHP).

Sarafin is given as a 5-day treatment and is used mainly to treat vibriosis. Managers on eight farms report using both OTC and Sarafin medicated feeds, while managers on three farms report using only OTC medicated feed, and one manager reports using only Sarafin medicated feed. Other reported disease treatments are lime, primarily hydrated lime, applied either to pond water during the production cycle or applied to the pond bottom between cycles, chlorination of puddles remaining on pond bottom after draining with HTH chlorine, and drying of pond bottom between cycles. Only one farm manager reports using pro-biotics, but could not name the product being used.

More than half (59 percent) of farm managers reported they had access to technical information on the use of chemotherapeutants. Of those managers having access to this technical information, only eight (47 percent) would like access to additional information, while 10 of 12 managers (83 percent) not having access to this information would like access to technical information on the use of chemotherapeutants.

lutants as are municipal and industrial effluents, but they often are more concentrated in suspended solids, nutrients, and organic matter than receiving waters (Schwartz and Boyd 1994a). Discharge levels can be lowered using several strategies: improvement in pond management methods, reduced water exchange, and treatment of effluents (Hopkins et al.

Water entering a pond should be carefully screened to remove animals that can act as disease vectors or predators. The screen shown here is inadequate because it removes only the largest fish, leaving other organisms to enter the pond.

Honduran Industry Practices – Health Management, Cont.

No manager reports poisoning a pond with disease problems. Dead shrimp collected on 18 farms (62 percent) are disposed of by either incineration or burying. In the case of a mass mortality, these farm managers report that birds consume most of the dead shrimp. On five farms (17 percent), managers leave dead shrimp in ponds for birds to consume; birds consume most of these dead shrimp. Managers of six farms report that dead shrimp are disposed of on the pond dikes, where they dry up or are consumed by birds.

Only screens placed at pond inlets prevent entry of feral animals into ponds. A single inlet screen is used at inlets on 23 farms (93 percent), double screens are used at inlets on five farms, and one farmer reported doing nothing to exclude other animals from ponds. The smallest mesh size used on inlet screens is 300 microns, but more common is an 800-micron mesh-size screen. On many farms mesh size increases (up to a maximum of 6.4-mm mesh) as the culture period progresses in order to facilitate water exchange.

Disease prevention is of great importance to the Honduran industry, and steps are generally taken to prevent disease, since few treatments are available. Preventive steps include low stocking rates, water quality management, screening and testing of PL, identification of the cause of mortality, disinfection of pond bottoms and treatment with medicated feeds. Adoption and implementation of preventive measures vary considerably among farmers, and may be increased through training, technical assistance and increasing the local capacity for pathological analysis.

Decisionmaking and Operations Management

10.0

The participatory process of developing GMPs and the findings of the field survey lead to some important observations regarding how decisionmaking impacts operations management and affects the nature of the GMPs. First, most industry participants and interviewees were farm managers or technical personnel. These individuals were targeted because it was believed they make the day-to-day decisions about pond management that affect the feasibility of the operation and environmental quality. This proved to be mostly accurate; however, some decisions may be made by others; for example, it is unknown to what extent farm managers make decisions regarding major capital expenditures. This indicates the need to raise awareness and solicit input from the farm owners in addition to other personnel. There are some GMP topics, such as renovation of ponds or siting decisions, that can only be made with the approval of the owners.

Another key factor is the rationale for making decisions. Part of this depends on the technical capacity of the personnel. Although most technical personnel appear to be well trained and competent, certain practices were observed which suggest that even these individuals can benefit from training and up-to-date information on technical topics.

In some cases, technical personnel choose to take a particular course of action simply on the premise that it may help and will not do any harm. This is most common when there is doubt regarding the outcome of a specific course of action, or when the scientific basis for a practice is weak. A common example in shrimp farming is the use of chemotherapeutants and pro-biotics. Given that few effective means of treating disease are available, and given that there is a possibility that a treatment may help, it is often perceived as the only course of action, particularly when the alternative is loosing an entire crop. This illustrates the need to continue applied research to resolve some of the critical unknowns of shrimp farming practices.

Another area needing attention is the farmers' ability to manage a pond as an ecosystem and to strategize for optimal outcome. The relationships between feeding, fertilizing and water quality, for example, are not always clear to operators. In addition, the relationship is difficult to monitor precisely. These issues are complex and, even under ideal conditions, managing a pond ecosystem is complicated. Honduran farmers face unique challenges imposed by their location, socioeconomic circumstances and surrounding ecosystem. Good technical ability and some luck are needed to produce a profitable crop. An objective of any training or extension program must be to increase the understanding of farmers on how to strategically manage their ponds in relationship to the surrounding ecosystem.

Effects of a Natural Disaster (Hurricane Mitch) on Shrimp Farm Management

Hurricane Mitch struck Honduras in October 1998 causing widespread damage to the industry and the nation. Losses and the cost of recovery imposed a heavy financial burden on shrimp farmers. As a result, a significant number of farmers appear to have changed their management strategy.

In the survey, farm managers were asked how they had modified their farm management practices as a result of Hurricane Mitch. Twenty-five managers (86 percent) gave a single response, while four (14 percent) gave multiple responses. Eleven managers stated that their farm management practices have remained unchanged, while 14 managers stated that they now seek greater economic efficiency through optimizing management practices and greater awareness of costs. This is in apparent contradiction to responses regarding criteria used in the decision to harvest a pond. For this, only five managers cite optimization of economic returns as a criterion. Three managers stated explicitly they now concentrate on maximizing farm profit rather than maximizing shrimp production. This is a major paradigm shift for shrimp farm managers who historically have focused on maximizing production. Given Hurricane Mitch's close proximity to the occurrence of the WSSV outbreaks, it is difficult to say with certainty what degree Hurricane Mitch has affected these changes in farm management practices/philosophy. Both events are responsible for provoking these changes.

11.0

The GMPs recommended here agree with the change in management strategy, since most GMPs promote efficiency in terms of reducing inputs such as feed and fertilizer, while reducing costs such as pumping costs.

It was thought that the hurricane might yield some insight into how construction and siting practices could be improved to lessen damage from future natural disasters. Twenty-six managers (90 percent) report making no changes to farm infrastructure as a result of Hurricane Mitch other than to restore damaged infrastructure to its original state. Two managers report increasing the height of perimeter dikes in the areas where floodwaters first entered the farm. It should be noted that in many areas, water levels rose 2 to 3 meters. Changes in construction practices cannot prevent damage in such severe cases; however, in lesser disasters some changes might prove useful. One action that might prevent loss in the future is to have preparedness plans in place to prevent loss of equipment and personnel, assuming adequate warning is given.

12.0 Conclusions and Recommendations

Several important findings emerged from this work. First, it is possible for industry, researchers and natural resources managers to work together to derive mutually acceptable GMPs that are scientifically-based and environmentally friendly. Second, the validity of this process is confirmed through the results of the field survey which indicate that the GMPs largely reflect the best technical knowledge of everyday practitioners in this field. Third, practices varied widely among shrimp farmers, and improvement will require applied research and training assistance. Fourth, the GMPs as they now stand represent a good first step towards identifying and improving practices, but further work is needed to refine and test better practices as knowledge on this topic evolves.

Disseminating information on GMPs to ensure widespread adoption will require significant effort through extension programs and training. Currently, ANDAH and a number of governmental and educational institutions conduct training and extension programs, but these are all limited in their effectiveness for reasons ranging from lack of resources to a shortage of integrated planning. Continued development of GMPs and expanding the range of topics they cover is an important next step. Perhaps more importantly is to develop a cooperative research and extension program wherein the various institutional stakeholders jointly develop extension assistance with the industry associations playing a strong role in determining the priorities. This opportunity will occur as part of the Hurricane Mitch Relief Funding soon to be provided by the United States Agency for International Development/ United States Department of Agriculture. This will provide an array of technical assistance projects directed at shrimp producers and other associated sectors.

Additionally, ANDAH has taken steps to adopt, implement and institutionalize GMPs. To date, 13,000 ha of the 18,000 ha of shrimp farms in operation in the southern region of Honduras are covered by an agreement of ANDAH member to use GMPs. Now, two challenges remain: 1) to implement use of GMPs more broadly and uniformly; and 2) to work towards adoption of GMPs by the owners of the remaining 5,000 ha. These are mostly small and medium-sized shrimp farms that are being targeted for training in GMPs through joint efforts of ANDAH/ USDA. ANDAH also is working toward improvements through creation of "Environmental Improvement" teams, which will oversee implementation and periodic revision of GMPs. There is also interest in wider environmental monitoring, building on, and integrated with, the existing monitoring efforts and database development carried out by the Choluteca Pathology Laboratory and the Water Quality Laboratory, La Lujosa, and other efforts such as an inventory of mangrove resources.

12.1 Specific Recommendations

The following technical recommendations are based on the field survey findings. These are compared to the recommended GMPs. Overall, the results of this survey indicate a high level of adoption of GMPs by shrimp farmers in southern Honduras on issues of health management, fertilization and feeding (Appendix B). In many instances, specific GMPs are being implemented on 60 percent or more of the surveyed farms. A number of recommendations are offered here to stimulate discussions among all stakeholders in the shrimp farming industry as they work to increase implementation of GMPs on shrimp farms.

Recommendation: ANDAH should take the lead to increase further implementation of GMPs by working with all shrimp farmers in Honduras. This could be accomplished through training courses, informational bulletins, and technical assistance to farmers.

Screening PL purchased from hatcheries for diseases prior to introduction onto a farm is an important mechanism to control the introduction and spread of diseases throughout a farm and throughout the industry.

Recommendation: Shrimp farmers are well advised to purchase PL only from reputable hatcheries where strict disease control measures are practiced. Purchased PL should be accompanied by a certification attesting to the disease-free health status of the PL. Shrimp farmers should require PCR tests for WSSV, TSV, and IHHNV for each shipment of PL purchased from foreign hatcheries. A routine program for disease screening should be established for Honduran hatcheries supplying associated farms and third-party customers. While about half of surveyed farms require a PCR test for WSSV for PL purchased from hatcheries, half the surveyed farms do not. This is one area where implementation of a GMP could have an immediate impact. It is expected that PCR analyses for viral diseases will increase once the ANDAH Aquatic Pathology Lab completes installation of its PCR equipment. It is important that the ANDAH lab become the leader in providing analytical capabilities for existing and future diseases. In fact, the ANDAH lab may wish to consider initiating a monitoring program to randomly sample shipments of PL from foreign sources and test PL for all known viral diseases. A similar program should be instituted to monitor prevalence of viral diseases in Honduran wild-caught PL. To be truly effective, such a program would require full participation by all segments of the industry, and hopefully, ANDAH will rise to the challenge of educating all shrimp producers regarding the importance of health maintenance to the shrimp industry.

Recommendation: Farms should quarantine PL from sources not certified as disease free until lab analyses show them to be disease free. Only when the PL are confirmed to be disease free should they be stocked into ponds. Isolated quarantine tanks designed so inlet water and tank effluent can be sterilized could be installed. Preferably, this quarantine area would be geographically isolated from the farm to minimize the possibility of accidental disease introduction onto the farm. If this is not possible, a quarantine area should be established in an area of the farm where access into and out of the area can be strictly controlled. The quarantine area should operate independent of the remainder of the farm and be supplied with its own equipment, supplies, and personnel. Disease control and management is an area that requires further research and development, especially on the large, open-system farms found in Latin America.

Farm managers generally appear successful in maintaining pond water quality to ensure that shrimp populations are not stressed. In fact, the great majority of farm managers surveyed reported that frequent, routine health checks are performed on pond shrimp, allowing managers the opportunity to decide whether or not to treat outbreaks of bacterial diseases. Use of medicated feed at labeled rates to treat bacterial diseases is conservative, with only 40 percent of surveyed farms using this method. Outbreaks of viral diseases, e.g., TSV, etc., are left to run their course. Given the absence of effective treatments, other than maintaining very good pond water quality and the open systems used for growing shrimp, farm managers can do little to combat a viral disease outbreak.

Sterilizing pond bottoms is an established, effective means to disrupt the disease cycle, yet farm managers on surveyed farms practiced only part of the sterilization process. Hydrated lime is used as a pond-bottom disinfectant on 70 percent of surveyed farms, but application rate is only 40 percent of the minimum recommended treatment. Pond mud pH can be raised above pH 10 by applying 1 MT/ha of burnt lime (CaO) or 1.32 MT/ha of hydrated lime [$Ca(OH)_2$], but effective elimination of pathogens is achieved by treatment with 2 MT/ha of burnt lime or 2.64 MT/ha of hydrated lime (Boyd 1995). Boyd (1995) recommends delaying filling and stocking the pond for 10 to 14 days after bottom sterilization. Thus, there is room for improvement regarding the use of hydrated or burnt lime in pond bottom sterilization.

<u>Recommendation</u>: Farm managers should apply lime according to already established guidelines.

During the farm visits, it was observed that application of hydrated lime to pond bottoms is patchy and concentrated in those areas nearest the pond dikes. Lime (burnt or hydrated) must be dispersed evenly over the entire pond to ensure effective treatment, and pond mud should be moist to allow the lime to dissolve and seep to at least 10 cm in depth (Boyd 1995). Hydrated lime and quick lime act to sterilize pond bottoms by increasing pH above 10 upon dissolution. This pH spike is transitory, remaining above pH 10 for 1 to 2 days, long enough to kill pathogens (Boyd and Masuda 1994). Hydrated lime and burnt lime react to neutralize acidity:

$$Ca(OH)_2 + 2H^+ = Ca^{+2} + 2H_2O$$
$$Ca(OH)_2 + 2CO_2 = Ca^{+2} + 2HCO_3^-$$

$$CaO + 2H^+ = Ca^{+2} + H_2O$$
$$CaO + 2CO_2 + H_2O = Ca^{+2} + 2HCO_3^-$$

Burnt and hydrated lime originate from limestone. Burnt lime is made by heating limestone to drive off carbon dioxide to yield calcium oxide; adding water to burnt lime makes hydrated lime. While limestone can be composed of calcite ($CaCO_3$) or dolomite [$CaMg(CO_3)_2$], limestone rarely is pure calcite and often contains some magnesium carbonate and other impurities. Chemical reactions of magnesium carbonate and calcium carbonate are similar. Boyd and Masuda (1994) evaluated two hydrated and three burnt limes commercially available in Honduras; one of the burnt limes actually turned out to be hydrated lime (Table 7). All five increased pH to 12.2 or greater using a

1:10, lime to distilled water slurry. Soil pH increased to about 11 when these limes were applied at 1 MT/ha (Boyd and Masuda 1994).

The neutralizing values of the Honduran limes, defined as the amount of acid a lime material will neutralize compared to pure calcium carbonate, tested by Boyd and Masuda (1994; Table 7) generally were close to the neutralizing values for pure calcium hydroxide (135 percent) and calcium oxide (179 percent). The efficiency rating (the percentage of a sample of lime that passes a 60 to mesh screen) of the tested limes ranged from 34 to 100 percent (Boyd and Masuda 1994). However, the authors noted that while some of these samples had low efficiency ratings, the clumps of lime break up into small particles when wetted.

Twenty-two farm managers (76 percent) reported making applications of a hydrated lime slurry to full ponds. The most common reason for the application, cited by 14 of 22 managers, was the control of bacteria; the second most common reason, cited by eight of 22 managers, was the control of phytoplankton blooms. The average application rate was 59 ± 50 kg/ha.

Recommendation: There is no scientific evidence to support continued application of hydrated lime to full ponds for these or any other reasons cited in Table 7. Without a scientific basis to support the decision to apply hydrated lime in this manner, what could explain the decision? It is difficult to argue that such applications negatively impact production economics, as the lime is inexpensive and relatively little labor is involved. Thus, there is no substantial economic incentive to justify the adoption or rejection of this practice. During interviews, several managers commented that they doubted that applications of hydrated lime were effective. Among the reasons given for continuing the practice was that the company president or farm owner saw all other farm managers applying hydrated lime in response to disease outbreaks, so why weren't they doing the same on their farm? Both farm managers and farmowners feel they must take some action in response to disease outbreaks, and application of hydrated lime to ponds provides them a mechanism to respond.

Table 8.
Properties of hydrated and burnt lime commercially available in Honduras[1].

Product	Primary Composition	pH[2]	Neutralizing Value (percent)	Efficiency Rating (percent)
Hydrated lime (Ineal Co., Cortes)	$Ca(OH)_2$	12.2	113	100
Hydrated lime (Colisa Co., Cortes)	$Ca(OH)_2$	12.3	130	96
Burnt lime (Siguatepeque)	$Ca(OH)_2$	12.3	124	73
Burnt lime (Siguatepeque)	CaO	12.3	151	34
Burnt lime (Siguatepeque)	CaO	12.3	168	36

[1] Source: Boyd and Masuda 1994.
[2] The pH was measured in a 1:10 lime:distilled water slurry.

Drying pond bottoms is another method to disinfect that also allows oxidation of any accumulation of organic matter.

Recommendation: Pond bottoms should be allowed to dry 7 to 14 days, until deep cracks develop; drying normally is best accomplished during the dry season.

Recommendation: Technical information about shrimp diseases and disease treatments is available to some farm managers, but this information needs to be more widely available, especially written in Spanish and directed at farm managers, who, while sophisticated, are not pathologists nor disease specialists. Technical bulletins that describe the life history, causative agent, presumptive field diagnosis, definitive diagnostic procedures, and state-of-the-art disease management or treatment should be prepared for common shrimp diseases in the Central American region. This information should be based on scientific data from empirical trials, not anecdotal evidence. Distribution of such bulletins can be organized and supervised by ANDAH to ensure that they reach the widest audience possible.

Pond fertilization by the shrimp industry in Honduras has progressed substantially during the past decade. In the early 1990s, regular fertilization was incorporated as part of the normal production strategy, along with regular water exchange and feeding. Thus, ponds were fertilized; then pond water was routinely exchanged, sometimes the same day fertilizers were applied. The net effect was to flush the fertilizers into the estuaries before they could stimulate primary productivity, the reason for applying the fertilizer. Research conducted by the Auburn University–Honduras PD/ACRSP demonstrated that fertilization was unnecessary in the pond management strategies used at that time. As a result of this research, ANDAH, in the mid-1990s, declared a moratorium on chemical fertilization by its members in order to reduce the nutrient load in shrimp farm effluents. During the latter half of the decade, research on optimization of input utilization by the Honduras PD/ACRSP and shrimp farmers contributed to additional, incremental changes in pond management strategies. Some of the more important changes were that water exchange rates were decreasing and becoming subject to greater control, and feed management was improving. Farmers began to experiment with pond fertilization again in order to better manage the phytoplankton populations in ponds. A desired goal of fertilization was to establish a stable phytoplankton bloom from the beginning of the culture cycle; this would improve pond DO dynamics. The increased natural productivity that resulted from this type of fertilization also would permit shrimp to maintain fast growth longer before addition of supplemental feed became necessary.

Fertilization is practiced on the majority of farms surveyed. Fertilizer management is considerably more refined today compared to a decade ago. Fertilizer still is applied prior to stocking to stimulate phytoplankton production, but rather than continuing with routine applications thereafter, on 59 percent of surveyed farms (81 percent of farms that use fertilizers), fertilizers are now applied only in response to specific Secchi disk visibility target depths. In addition, water exchange is now more carefully managed, with water being exchanged only in response to low pond DO concentration, or delayed for 1.5 to 7 days following fertilization. Thus, applied fertilizer has time to be absorbed by phytoplankton rather than being flushed out of the pond in exchange water. Fertilizer is dissolved in smaller portions of pond water before the solution is distributed throughout the pond from a boat. This practice is used on 71 percent of farms that fertilize, and ensures that fertilizer nutrients are available to phytoplankton populations in the water column. When fertilizers are broadcast over the pond surface, fertilizer granules can sink to the pond bottom before dissolving completely, and nutrients, especially phosphorus, are instead absorbed by pond mud.

Pond fertilization management could be improved on some farms. A Secchi disk is a good tool to use to manage pond fertilization, however, Secchi disk visibility is valid only as long as phytoplankton is the source of pond turbidity.

<u>Recommendation</u>: It is recommended that all farms use a Secchi disk to determine the need for pond fertilization, and that Secchi disk visibility be measured between 1100 to 1300 h, when the sun is directly overhead. In addition, all fertilizer should be dissolved in pond water before being added to the pond. Additional research is necessary to determine optimal fertilization rates for farms located on riverine estuaries, where nutrient concentrations naturally are high, and embayments of the Gulf of Fonseca, where ambient nutrient concentrations are low. Also, research is necessary to determine whether fertilization rates for farms on riverine estuaries can be varied between rainy and dry seasons because of the seasonal variations in estuarine nutrient concentrations.

It should be noted that in estuaries that serve as source water to shrimp farms, nutrient concentrations are higher during the dry season than during the rainy season. Data collected as part of the Auburn University–Honduras PD/ACRSP estuarine water quality monitoring project demonstrate that concentrations of water quality variables increase during the dry season as a result of reduced river discharge, absence of rainfall runoff, and evaporation. During the rainy season, increased river discharge and watershed runoff flushes the estuaries and reduces estuarine nutrient concentrations. However, a number of farm managers mistakenly believe that the nutrient concentration of their source water is lower during the dry season. Farm managers may think that less turbid-appearing estuarine water, which results from a lower total settable solids concentration during the dry season, may be less fertile; however, the opposite is true.

Feed management, in general, appears to be well developed as demonstrated by the feed conversion ratios and feeding practices reported. Mean reported feed conversion ratios are 1.36 and 1.60 for the rainy and dry seasons, respectively. Shrimp feeding rate is adjusted weekly based on shrimp biomass on 28 of 29 farms, and on consumption from feed trays on one farm. Because of increased natural productivity that results from pond fertilization, feeding is initiated three weeks after stocking on 19 of 29 farms. The daily feed ration is divided into two meals, one offered in the morning and the other in the afternoon. Feed is distributed from a boat on 27 of 29 farms. The maximum daily feeding rate is moderate, and averages 23 kg/ha. Feeding at this rate is unlikely to result in low pond DO concentrations; nearly 90 percent of farm managers report no problems with pond DO concentrations at prevailing feeding rates. On all of the farms, shrimp are fed commercially formulated, pelleted rations that contain 20 to 25 percent protein. Fresh, ground fish are not used as shrimp feed on any of the surveyed farms. Feed quality is maintained through good storage conditions and a 21-day turnover rate.

Recommendation: While farmers are to be commended for lowering feed ratios to current levels, they should continue to strive for additional reductions, especially during the dry season when nutrient concentrations in estuaries are highest. Nutrient waste from feed increases as FCR increases, which can result in a higher nutrient load in pond effluents. Higher nutrient loads during the dry season could aggravate estuarine water quality conditions, particularly in the estuary headwaters. Thus, it is important to improve dry-season FCR. The use of feed trays may increase feeding efficiency. However, the FCR reported from the one farm that uses feeding trays are 1.2 and 1.6 for the rainy and dry seasons, respectively. Farm managers may wish to consider alternative pond management strategies during the dry season, e.g., lower feeding rate, or substitution of chemical fertilization for feed.

Water quality and pathology monitoring are already being conducted by ANDAH. Data from these efforts has already been useful in defining and implementing GMPs. Better use of this data can be made, however. Support is needed for more rapid interpretation of the data and dissemination for decision-making purposes. Additionally, expanded environmental monitoring of other indicators could be useful in evaluating the status of the ecosystem and sources of impacts, particularly those related to other industries that lag behind the shrimp industry in monitoring and developing GMPs.

Note to Readers and Acknowledgements

13.0

This document is a work in progress. Financial support was received from United States Agency for International Development's Hemispheric Free Trade Expansion Project. Substantial contributions to this project have been made by collaborators and reviewers from the ANDAH, Auburn University and the Honduras-Pond Dynamics/Aquaculture Cooperative Research Support Program (PDA/CSRP) project. While the outstanding efforts and contributions of these groups are gratefully acknowledged, all errors and omissions are those of the authors. Further modifications and refinements will continue to be made to the GMPs as the project and its collaborators strive to identify and define GMPs for sustainable shrimp culture in Latin America: this is an evolving process.

Recognition and grateful acknowledgement is due to the leadership and members of ANDAH, which collaborated in development of the GMPs. ANDAH also financially supported the field survey and provided critical logistical assistance. Without their technical expertise, organizational capacity and long-term support to the process of developing GMPs for their industry, this study would not have been possible. The fact that their strongest contributions came in the aftermath of recovery from Hurricane Mitch is a demonstration of their commitment to a sustainable industry and to environmental quality.

Seven anonymous reviewers from industry, academia and environmental non-profit organizations made important contributions by reviewing multiple drafts of this work; their technical input and guidance greatly assisted the authors.

Special thanks are rendered to Dr. Bryan Duncan, Auburn University, for his assistance in facilitating formation of the partnership between the Coastal Resources Center, University of Rhode Island, ANDAH and Auburn University.

References

Ahmad, T. and C.E. Boyd. 1988. Design and performance of paddlewheel aerators. Aquacultural Engineering 7:39-62.

Association of Southeast Asian Nations (ASEAN). 1997. Harmonization of good shrimp farm management practices. ASEAN Fisheries Network Project, Thailand Department of Fisheries, Bangkok, Thailand.

Barica, J. 1975. Summer kill risk in prairie ponds and possibilities of its prediction. Journal of the Fisheries Research Board of Canada 32:1283-1288.

Boyd, C.E. 1990. Water Quality in Ponds for Aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.

Boyd, C.E. 1992. Shrimp pond bottom soil and sediment management, pp. 166-181. In: J.A. Wyban, (ed.), Proceedings Special Session on Shrimp Farming. World Aquaculture Society, Baton Rouge, Louisiana, USA.

Boyd, C.E. 1995a. Bottom Soils, Sediment, and Pond Aquaculture. Chapman and Hall, New York, New York, USA.

Boyd, C.E. 1995b. Source water, soil and water quality impacts on sustainability in aquaculture, pp. 24-33. In: Sustainable Aquaculture '95, Pacific Congress on Marine Science and Technology, Honolulu, Hawaii, USA.

Boyd, C.E. 1996. Shrimp farming and the environment-A White Paper. National Shrimp Council, National Fisheries Institute, Arlington, Virginia, USA.

Boyd, C.E. 1997a. Environmental issues in shrimp farming, pp. 9-23. In: D.E. Alston, B.W. Green, and H.C. Clifford III (eds.), IV Simposio Centroamericano de Acuacultura. Associacion Nacional de Acuicultores de Honduras, Tegucigalpa, Honduras.

Boyd, C.E. 1997b. Advances in pond aeration technology and practices. INFOFISH International 2/97:24-28.

Boyd, C.E. 1998. Draft code of practices for shrimp farming. Global Aquaculture Alliance, St. Louis, Missouri, USA.

Boyd, C.E. and T. Ahmad. 1987. Evaluation of aerators for channel catfish farming. Bulletin 584. Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.

Boyd, C.E. and J.W. Clay. 1998. Shrimp aquaculture and the environment. Scientific American 278 (June):58-65.

Boyd, C.E. and L. Massaut. 1998. Soils in pond aquaculture. Aquaculture Asia 3 (January-March):6-10.

Boyd, C.E. and K. Masuda. 1994. Characteristics of liming materials used in aquaculture ponds. World Aquaculture 25:76-79.

Boyd, C.E. and J.F. Queiroz. 1997. Effluent management in pond aquaculture. Aquaculture Asia 2 (April-June):43-46.

Boyd, C.E. and C.S. Tucker. 1995. Sustainability of channel catfish farming. World Aquaculture 26:45-53.

Boyd, C.E. and C.S. Tucker. 1998. Pond Aquaculture Water Quality. Kluwer Academic Publishers, Boston, Massachusetts, USA.

Boyd, C.E., L. Massaut, and L. Weddig. 1998a. Procedures to lessen the environmental impacts of pond aquaculture. INFOFISH International 2/98:27-33.

Boyd, C.E., A. Gross, and M. Rowan. 1998b. Laboratory study of sedimentation for improving quality of pond effluents. Journal of Applied Aquaculture 8:39-48.

Boyd, C.E., E.E. Prather, and R.W. Parks. 1975. Sudden mortality of a massive phytoplankton bloom. Weed Science 23:61-67.

Brooks, K.N, P.F. Folliet, H.M. Gregersen, and L.F. DeBano. 1997. Hydrology and the Management of Watersheds. Iowa State University Press, Ames, Iowa, USA.

Brunson, M. 1997. Catfish quality assurance. Mississippi Cooperative Extension Service, Publication 1873, Mississippi State University, Mississippi State, Mississippi, USA.

Clifford, H.C. III. 1994. Semi-intensive sensation. A case study in marine shrimp pond management. World Aquaculture 25: 6-12.

Courtenay, W.R. 1992. A summary of fish introductions into the United States. In: M.R. DeVoe, (ed.), Proceedings of the Conference and Workshop: Introductions and Transfers of Marine Species, South Carolina Sea Grant Communications. Charleston, South Carolina, USA.

Csavas, I. 1990. Shrimp aquaculture developments in Asia, pp. 207-222. In: M.B. New, H. Saram, and T. Singh (eds.), Technical and economic aspects of shrimp farming. Proceedings of the Aquatec '90 Conference, Kuala Lumpur, Malaysia.

Dent, D. 1986. Acid sulfate soils. A baseline for research and development. International Institute of Land Reclamation and Development, Publication 39, Wageningen, The Netherlands.

Dierberg, F.E. and W. Kiattisimukul. 1996. Issues, impacts, and implications of shrimp aquaculture in Thailand. Environmental Management 20:649-666.

Dixon, H. 1997. Environmental code of practice for the shrimp farming industry of Belize. Unpublished Manuscript.

Donovan, D.J. 1997. Draft environmental code of practice for Australian prawn farmers. Kuruma Australia Pty., Ltd., East Brisbane, Queensland, Australia.

Federal Joint Subcommittee on Aquaculture. 1994. Guide to drug, vaccine, and pesticide use in aquaculture. Texas Agricultural Extension Service, Texas A and M University, College Station, Texas, USA.

Field, C. (ed.). 1996. Restoration of mangrove ecosystems. International society for Mangrove Ecosystems, University of Ryukyus, Okinawa, Japan.

Folke, A. and N. Kautsky. 1989. The role of ecosystems for sustainable development of aquaculture. Ambio 18:234-243.

Food and Agriculture Organization (FAO) of the United Nations. 1996. Time series on aquaculture-quantities and values. FAO Fisheries Information, Data and Statistics Unit, Rome, Italy.

Green, B.W. and D.R. Teichert-Coddington. 1990. Lack of response of shrimp yield to different rates of inorganic fertilization in grow-out ponds. pp 20-21 In H.S. Egna, J. Bowman and M. McNamara (eds.). Pond Dynamics/Aquaculture Collaborative Research Support Program, Seventh Annual Administrative Report, PD/ACRSP, Office of International Research and Development, Oregon State University, 400 Snell Hall, Corvallis, Oregon, USA.

Green, B.W., D. R. Teichert-Coddington, C.E. Boyd, J. Wigglesworth, H. Corrales, D. Martinez and E. Ramirez. In press. Influence of Daily Water Exchange Volume on Water Quality and Shrimp Production, Eighth Work Plan, Honduras Research 3 (HR3). Sixteenth Annual Administrative Report, Pond Dynamics/Aquaculture CRSP 1998, Oregon State University, Corvallis, Oregon, USA.

Hairston, J.E., S. Kown, J. Meetze, E.L. Norton, P.L. Dakes, V. Payne, and K.M. Rogers. 1995. Protecting water quality on Alabama farms. Alabama Soil and Water Conservation Committee, Montgomery, Alabama, USA.

Hajek, B.F. and C.E. Boyd. 1994. Rating soil and water information for aquaculture. Aquaculture Engineering 13:115-128.

Hopkins, J.S., C.L. Browdy, R.D. Hamilton, and J.A. Heffernan. 1995a. The effects of low-rate sand filtration coupled with careful feed management on effluent quality, pond water quality, and production of intensive shrimp ponds. Estuaries 18:116-123.

Hopkins, J.S., P.A. Sandifer, M.R. DeVoe, A.F. Holland, C.L. Browdy, and A.D. Stokes. 1995b. Environmental impacts of shrimp farming with special reference to the situation in the continental United States. *Estuaries* 18:25-42.

Hopkins, J.S., P.A. Sandifer, C.L. Browdy, and J.D. Holloway. 1996. Comparison of exchange and no-exchange water management strategies for the intensive pond culture of marine shrimp. *Journal of Shellfish Research* 15:441-445.

Hopkins, J.S., R.D. Hamilton, P.A. Sandifer, C.L. Browdy, and A.D. Stokes. 1993. Effects of water exchange rates on production, water quality, effluent characteristics, and nitrogen budgets of intensive shrimp ponds. *Journal of the World Aquaculture Society* 24:304-320.

Jory, D. 1998. World shrimp farming in 1997. *Aquaculture Magazine Buyer's Guide* 27:32-41.

Liao, I.C. 1986. General introduction to the prawn pond system in Taiwan. *Agricultural Engineering* 5:219-234.

Lin, C.K. 1986. Acidification and reclamation of acid sulfate soil fish ponds in Thailand, pp. 71-74. In: J.L. Maclean, L.B. Dixon, and L.V. Hosillos (eds.), *The First Asian Fisheries Forum*. Asian Fisheries Society, Manila, Philippines.

Lovell, R.T. and D. Broce. 1985. Cause of musty flavor in pond-cultured Penaid shrimp. *Aquaculture* 50:169-174.

McCarty, D.F. 1998. *Essentials of Soil Mechanics and Foundations*. Prentice Hall, Upper Saddle River, New Jersey, USA.

McVey, J.P. 1988. Aquaculture in mangrove wetlands: a perspective from Southeast Asia, pp. 375-394. In D.D. Hook (ed.), *The Ecology and Management of Wetlands, Vol. 2. Management, Use and Value of Wetlands*, Timber Press, Portland, Oregon, USA.

Mikkelsen, R.L. and J.J. Camberato. 1995. Potassium, sulfur, lime, and micronutrient fertilizers, pp. 109-137. In: J. E. Rechcigl (ed.), *Soil Amendments and Environmental Quality*. Lewis Publishers, Baco Raton, Florida, USA.

Mitchell, R. (ed.). 1992. *Environmental Microbiology*. Wiley-Liss, New York, New York, USA.

Phillips, J.J. 1995. Shrimp culture and the environment, pp. 37-62. In: T.U. Bagarinao and E.E.C. Flores (eds.), *Towards Sustainable Aquaculture in Southeast Asia and Japan*. SEAFDEC Aquaculture Department, Iloilo, Philippines.

Phillips, M.J., C.K. Lin, and M.C.M. Beveridge. 1993. Shrimp culture and the environment: Lessons from the world's most rapidly expanding aquaculture sector, pp. 171-179. In: R.S.V. Pullin, H. Rosenthal, and J.L. Maclean (eds.), *Environment and Aquaculture in Developing Countries*. ICLARM Conference Proceedings 31, Manila, Philippines.

Poernomo, A. 1990. Site selection for coastal shrimp ponds, pp. 3-19. In: M.B. New, H. De Saram, and T. Singh (eds.), *Technical and Economic Aspects of Shrimp Farming*. Proceedings of the Aquatec '90 Conference, Kuala Lumpur, Malaysia.

Ponce-Palafox, J., C.A. Martinez-Palacios, and L.G. Ross. 1997. The effects of salinity and temperature on the growth and survival of juvenile white shrimp, *Penaeus vannamei*, Boone, 1931. *Aquaculture* 157:107-115.

Primavera, J. H. 1993. A critical review of shrimp pond culture in the Philippines. *Reviews in Fisheries Science* 1:151-201.

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

Rodriguez, R., O.J. O'Hara and D.R. Teichert-Coddington. 1991. Efecto de la tasa de fertilización inroganica y calidad de agua sobre el crecimiento y economia en el cultivo semi-intensivo de camaron *Penaeus* spp. en Granjas marinas San Bernardo. pp 407-442 In *Proceedings, First Central American Symposium on Cultivated Shrimp*, 24-26 April, 1991. Tegucigalpa, Honduras.

Schwartz, M.F. and C.E. Boyd. 1994a. Channel catfish pond effluents. *The Progressive Fish-Culturist* 56:273-281.

Schwartz, M.F. and C.E. Boyd. 1994b. Effluent quality during harvest of channel catfish from watershed ponds. *The Progressive Fish-Culturist* 56:25-32.

Simon, A.L. 1976. *Practical Hydraulics*. John Wiley and Sons, New York, New York, USA.

Sinderman, C.J. 1988. Disease problems created by introduced species, pp. 394-398. In: C.J. Sinderman and D.V. Lightner (eds.), *Disease Diagnosis and Control in North American Marine Aquaculture*. Elsevier Scientific Publishers, Amsterdam, The Netherlands.

Soil Survey Staff. 1994. *Keys to Soil Taxonomy*. Soil conservation Service, United States Department of Agriculture, Washington, D.C., USA.

Tchobanoglous, G. and E.D. Schroeder. 1987. *Water Quality*. Addison-Wesley Publishing Company, Reading, Massachusetts, USA.

Teichert-Coddington, D.R., C.E. Boyd, and D.M. de Pinel. 1997. Solubility of selected inorganic fertilizers in brackishwater. *Journal of the World Aquaculture Society* 28:205-210.

Teichert-Coddington, D.R., D. Martinez, and E. Ramirez. 1995. *Characterization of shrimp farm effluents in Honduras and chemical budget of selected nutrients*. Work Plan 7, Honduras Study 2. Pond Dynamics/Aquaculture Collaborative Research Program, International Research and Development, Oregon State University, Corvallis, Oregon, USA.

Tookwinas, S. 1996. Environmental impact assessment for intensive marine shrimp farming in Thailand. *Thai Fisheries Gazette* 46:119-133.

Tucker, C.S., S.W. Lloyd, and R.L. Busch. 1984. Relationships between phytoplankton periodicity and the concentrations of total and un-ionized ammonia in channel catfish ponds. *Hydrobiologia* 111:75-79.

Wheaton, F.W. 1977. *Aquacultural Engineering*. Wiley-Interscience, New York, NY, USA.

Yoo, K.H. and C.E. Boyd. 1994. *Hydrology and Water Supply for Pond Aquaculture*. Chapman and Hall, New York, New York, USA.

Appendix A

Assessment of the Adoption Level of Good Management Practices: Field Survey Materials and Methods

A questionnaire was developed with input from ANDAH to assess the level of adoption of selected GMPs developed by Haws and Boyd (1999). GMPs in the areas of health management, fertilization, and feeding were evaluated wholly or partially by the questionnaire. Implementation of the questionnaire was planned in collaboration with the board of directors and member of ANDAH. Logistical support for field implementation of the questionnaire was provided by ANDAH.

Health management GMPs evaluated:

A1. When possible, PL should be purchased that are disease free and from reputable hatcheries.

A2. Good water quality should be maintained in ponds.

A3. Causes of mortality should be identified.

A4. Before stocking, PL should be examined for signs of disease and to assess quality.

A5. If an effective disease treatment is available, it should be used promptly and properly to limit disease.

A6. Technical information on the use of chemotherapeutics should be developed for regional industry.

A7. Water should not be exchanged in ponds with disease problems, particularly if it is suspected that a new disease organism may be involved.

A8. Ponds that have had serious disease mortality should not be drained until disease organisms have been deactivated by chlorination or other means.

A9. Dead and diseased animals should be disposed of in a sanitary manner.

A10. Entry of wild animals and escape of domestic animals should be minimized by screening intakes or by other suitable means.

A11. Bottoms of diseased ponds should be dried for two or three weeks. Treat with 1 to 2 MT/ha of burnt lime to raise the pH and to disinfect the pond.

A12. Pond bottoms should be dried completely at least after three or four production cycles; more frequent drying is advisable.

A13. Neighboring shrimp farmers should cooperate and communicate with regard to disease problems to minimize the spread of disease.

A14. The use of antibiotics and other anti-bacterial agents should be limited to occasions when the presence of a pathogen susceptible to the agent is suspected.

A15. Water quality measurements should be made frequently in all ponds.

FERTILIZATION GMPS EVALUATED:

B1. Chemical fertilizers should only be used when necessary to increase phytoplankton abundance.

B2. Excessive application of urea and ammonium fertilizers should be avoided.

B3. Liquid fertilizers are preferred, but if granular fertilizers are used, one of several available methods should be used to ensure their dissolution.

B4. If it becomes necessary to use organic fertilizers, the use of manures should be avoided unless their quality can be confirmed.

B5. Fertilizers should be stored in a clean, dry place away from sparks, and spills should be avoided.

B6. If pH of bottom soils is less than 7, agricultural limestone should be applied between crops.

B7. Agricultural limestone, rather than burnt lime or hydrated lime, should be used for neutralizing acidity.

B8. Waters with total alkalinity above 50 to 60 mg/l should not be limed.

B9. Liming materials should be applied uniformly over the pond bottom surface, and tilling to a depth of 5-10 cm will speed reaction of liming materials.

B10. Liming materials should be applied on the basis of soil testing.

FEEDING GMPS EVALUATED:

C1. A high-quality, pelleted feed with a minimum of "fines" and good water stability should be used.

C2. Fish should not be used as feed.

C3. Feed should be stored in cool, dry buildings, safe from pests.

C4. Nitrogen and phosphorus levels in feeds should be as low as possible without sacrificing feed quality, although caution should be exercised because lower limits for these compounds still are unknown.

C5. Feed requirements should be calculated based on regular biomass estimates and feeding formulas.

C6. Using feeding trays should be considered to monitor feeding activities.

C7. Feed should be dispersed uniformly over the pond surface avoiding large, repeated applications over small areas.

C8. Daily feed allowances should be applied in more than one application per day where possible.

C9. Ponds should not be feed when pond dissolved oxygen concentrations are below 2.5 mg/l.

Questionnaires were completed during August 1999 at 29 farms in southern Honduras. The farm manager, sometimes accompanied by the company technical director (where such a position existed), was interviewed. Interviews were conducted at the farm for 26 of 29 farms; accessibility prevented farm visits to three farms. Once the interview was completed, the farm was toured to observe farm practices and implementation of GMPs.

Appendix B

Summary of Field Survey Results: Assessment of the Adoption Level of Good Management Practices in Health Management, Fertilization, and Feeding

GMP	Comment
	Health Management
A1.	All farms strive to purchase disease-free PL from labs; about 50 percent of farms require PCR for WSSV and other health status certification from PL suppliers. This is more difficult when wild PL are purchased.
A2.	All farms work to maintain good water quality in ponds.
A3.	About 90 percent of farms perform frequent health checks on stocked shrimp populations and are able to presumptively identify many diseases on-farm. There is growing use of ANDAH Aquatic Pathology and international labs for confirmatory diagnoses.
A4.	About 50 percent of farms subject PL to a stress test prior to stocking.
A5.	About 40 percent of surveyed farms used commercially available medicated feeds to treat bacterial diseases.
A6.	Technical information is available to some, but needs to be more widely available and in Spanish.
A7.	Water in ponds with disease outbreaks should not be exchanged unless required because of low DO concentrations.
A8.	No farm manager poisons a pond affected by disease, nor is any manager likely to do so.
A9.	The majority of farms dispose of dead shrimp by burning or burying.
A10.	Pond inlets on all farms are screened; double screens are used on some farms.
A11.	About 70 percent of farms disinfect pond bottoms with hydrated lime, but mean application rate is 40 percent of minimum recommended rate. About 59 percent of farm managers dry pond bottoms.
A12.	About 59 percent of farm managers dry pond bottoms for an extended period of time, mostly during dry season.
A13.	There is some communication among farm managers; this appears better among members of ANDAH. ANDAH could be more active in communicating relevant information to all shrimp farmers.
A14.	Medicated feed use is reported only in response to bacterial diseases and only on 40 percent of farms.
A15.	DO ismeasured daily on 83 percent of farms. Ammonia measured only on 10 percent of farms; however, feed rates used are unlikely to cause ammonia problems.
	Fertilization
B1.	About 72 percent of farms apply chemical fertilizers to increase phytoplankton abundance in production ponds.
B2.	Fertilization rates are low to moderate.
B3.	About 71 percent of farms dissolve granular fertilizer prior to its application to pond.

B4. Only one farm uses organic fertilizer, and only at a low rate at pond flooding.

B5. About 86 percent of farms that fertilize store fertilizer on skids in a covered storage area.

B6. Agricultural limestone is applied to adjust soil pH on one farm only; this has not been done in past two years.

B7. Liming is not done to increase total alkalinity, but hydrated lime is used for other purposes. The efficacy of some of these purposes has not been demonstrated.

B8. Liming materials aregenerally applied to disinfect pond bottoms; application over pond bottom could be more uniform; lime is not tilled in.

B9. Liming is generally not used to adjust soil pH.

Feeding

C1. Feed quality appears reasonable, but feed evaluation was not part of this survey.

C2. Fish are not used as feed.

C3. Feed is stored on skids in covered storage areas.

C4. Nitrogen levels moderate because 20-25 percent protein feeds used; phosphorus not evaluated in this survey.

C5. Shrimp biomass is determined weekly on all farms, and biomass estimates are used to calculate feed ration on 28 farms. One farm bases feed ration solely on consumption as measured by feed trays.

C6. One farm uses feed trays exclusively, another farm uses feed trays in some ponds.

C7. Feed is distributed from a boat on 97 percent of farms; boat travels a zigzag route through pond.

C8. On average, farms feed twice daily.

C9. Feed is suspended if mean pond DO concentration is less than 2.2 mg/l.