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Global Attempts to Address Shrimp Disease

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Abstract

In this article the problems facing shrimp farming today are discussed, with a particular focus on shrimp diseases. An attempt is made to quantify the shrimp disease problem globally. The main disease threats are presented: they include viral, bacterial, rickettsia, fungal, and protozoan diseases as well as nutritional, toxic and other environmentally related diseases. A few suggestions for research strategies are presented. The paper then briefly analyses the status of the efforts being made to address shrimp diseases, and why so little has been done to date. A few suggestions are made on possible strategies to address international collaboration on shrimp disease research. The article concludes with a discussion on funding needs and a few proposals of where to go from here.

Key Words

Shrimpfarming, Disease, Virus, Bacteria, Shrimp Research, Aquaculture

INTRODUCTION

The shrimp farming industry has been a repeated success story in developing countries for the past fifteen years, with an annual production in 1994 of 733 000 metric tons, up from 84 metric tons in 1972. A rough estimate of the total world market value of farmed shrimp is $3.7 billion, based on an average price of 5 US$ per Kg. Virtually all of the production takes place in developing countries. In Thailand, for example, shrimp farming and processing is estimated to employ 150,000 people (Rosenberry 1995). In Ecuador, shrimp farming is the second largest economic activity.

The industry saw unprecedented growth during the 1980s, but in 1992 its rapid growth began to slow, creating significant problems. Despite continued expansion of the total farming area, several countries such as China, Taiwan and the Philippines have had much lower production levels than previously. Reasons for this decline include poor management practices and lack of knowledge about farming techniques. Another contributing factor is deteriorating environmental quality, particularly of water through industrial pollution. However, a large part of the problem has to do with shrimp diseases, which has increased steadily over the past decade and is now perhaps the largest obstacle to sustainability of the industry (Rosenberry 1993).

This article will consider the problems facing shrimp farming today, with a particular focus on shrimp diseases. The status of efforts to address these diseases will be discussed, an analysis will be presented of why so little has been done to date and suggestions made of possible future strategies. The article will conclude with a discussion of the role of different actors in the industry and a few proposals of where to go from here.

THE PROBLEMS OF SHRIMP FARMING

Many of the problems in shrimp farming are rooted in the development of the industry. Taiwan and Ecuador were pioneers in the field, developing farming techniques as well as ways of intensifying the pond farming systems. While many techniques were developed in the United States, land prices and labor costs make actual farming non-profitable there. During this development stage, not enough attention was focused on water quality and the maintenance of environmental quality in the areas surrounding the shrimp ponds. Ponds were often located on previously unmanaged land such as mangrove forests, salt flats, estuaries and wetland areas. In some places, farming has been unsustainable, leading to abandonment of large areas. Attempts to replant and restore the destroyed wetlands have been and continue to be made, yet overall this still remains a serious problem in many countries.

The example of Java is a good illustration of some of the problems that can arise when extensive areas are put under shrimp cultivation without zoning or proper management practices. Over the past decade, the area dedicated to shrimp farming grew to more than 200,000 hectares some of this area had been under other form of aquaculture but significant mangrove areas were cut and replaced with extensive shrimp ponds. Initially, farming was quite successful, but then the problems of unsustainable farming practices, poor water quality, disease and extensive use of antibiotics caused a decline in the harvest. Harvest size decreased from an average of 33 grams per animal to 25 grams. The average yield per harvest is down from 5 metric tons per hectare (heads-on) to 3 metric tons. In mid 1994, the industry faced massive problems when nearly the entire shrimp crop in eastern Java was killed by disease, possibly a virus. Currently total shrimp production from farms and wild catches is less than what used to be the total sustainable catch from the wild alone (Rosenberry 1994). To reach large sustainable production levels will require significant improvement in management practices and zoning regulations as well as replanting of mangroves in traditional spawning grounds. Another case is India, where the entire crop of Andra Pradesh and Tamil Nadu, estimated at a value of US$64 million, was wiped out in 1995. Viral disease was the direct cause of the losses (Hugh-Jones).

Some of the problems raised above have been influenced by the structure of the industry. The capacity for health management of shrimp is important in understanding how to address these problems and will be discussed. Following this, I will focus on specific disease problems and current knowledge regarding the industry and, more specifically, trends for future success.

Industry structure

Many problems with shrimp farming derive from the fact that the industry developed rapidly with very little scientific and practical knowledge to support the new farming techniques. The industry quickly attracted farmers with limited capital investment possibilities and this is now proving to be one of the main reasons for the current unsustainable practices. Big investors were often equally anxious to get a quick return on their investment. Part of this problem is due to unclear rules on ownership of land in the coastal zone. In some countries, it was possible to claim ownership of common property land, such as estuaries and mangrove forests, by building shrimp ponds. This led to speculation and location of farms on unsuitable land. In some coastal areas where there have been extensive disease outbreaks, unmanaged ponds remain several years after the collapse of the industry, often due to such speculation.

In the early phase, the industry did not focus on long-term sustainability of operations, and often used quick fixes. This is particularly clear in the case of disease, where the use of antibiotics and probiotics has been widespread, while long-term investment in scientific capacity to diagnose, vaccinate and treat diseases has been almost non-existent. The industry's relations with most of the concerned governments have also been such that public funds to address some of the problems have been very limited. This may be due to a weak shrimp lobby as well as the absence of institutions capable of providing the resources. Other factors that led to an under evaluation of the industry may be the low tax collection rate and poor farm production statistics.

As the industry matures and consolidates, it is natural to expect that some of the larger private firms will invest in health management capacity as well as in simpler forms of treatment and “Probiotics”. Probiotics is generally meant to include general immune stimulants and changing the microbial composition of the farming environment in a way that enhances the survival of shrimp. Experiences from other farmed crops indicate that there will be products available on the market to address some of the health problems. To date, however, investments have just begun and corresponds only to a tiny fraction of total losses

HEALTH MANAGEMENT

The most important factor in the poor production of some of the shrimp farms is inadequate management. Factors such as water quality, pond preparations between growout periods and basic capacity to detect disease and take appropriate measures will determine whether shrimp farming can be locally sustainable. Particularly in countries where the knowledge level among farmers is low, the need for improved management practices remains acute. Vast improvements in management practices have been made through the efforts of large farming companies as well as institutes around the world. In particular, the work conducted in Ecuador, Taiwan, Thailand and the United States has contributed to the establishment of a state-of-the-art in sustainable shrimp farming. However, much remains to be done and the situation will probably get worse before it gets better. The enormous disease problems experienced in China, for example, could very well be repeated in India and Bangladesh in a few years’ time if nothing is done to improve current farming practices.

Carrying Capacity Limit

One of the most important aspects of improving health management is to understand the basic carrying capacity of the ecosystems surrounding the ponds. Factors affecting such capacity include water exchange and runoff, density of farms, soil composition and salinity as well as intensity of farming practices. The carrying capacity of a coastal area may often be reached some time before a catastrophe occurs, meaning that almost irreversible harm will be done to the surrounding ecosystem before there is any attempt at restoration of ecological functions.

Absorptive Capacity

To date, it has often been the practice to expand shrimp farming in a given area until the environmental effects are so severe and water quality so bad that massive investments in treatment are needed and some of the farms must either close down or change to algae cultivation. Often in the past, feasibility studies focused on farming situations where effluents would be absorbed by surrounding ecosystems and nutrient accumulation was not properly factored into the equation. Growing human population pressure and organic loads have also resulted in problems of water quality and risks of human pathogen contamination. However, there is a need to make reasonable estimates of the absorptive capacity of a particular ecosystem as well as what is needed in terms of water treatment. Many problems in shrimp farming could be addressed and possibly eliminated through practical measures to prevent exceeding the absorptive capacity of the ecosystems. Developing methodologies for assessing absorptive capacity for sustainable management is an important challenge for the aquaculture industry. Limiting and treating the inputs leading to the eutrophication is another obvious way out of today's problems. Developing systems for interchanging aquaculture of shrimp farming with other species is another way of limiting the damages. Such changes can help prevent the current overshoot collapses affecting many areas, and leading to wider spread of disease agents.

Microbial Enhancement of the Culture Environment

Establishing an appropriate environment for shrimp requires knowledge of the optimal microbial conditions in the farming area as well as particular needs of the species that are being cultivated. Changes that affect shrimp can often take place rapidly among the microbes, affecting pH as well as oxygen levels and other fundamental conditions. For example, such stress can be induced by heavy rains or changes in the tides. In order to control such factors, a basic knowledge of microbiology\limnology and the well-being of shrimp, i.e., health status, is required, with testing capacity available on site. The use of cultured micro-organisms has proven to be an effective way to control outbreaks of disease caused by environmental stress. The main approach should be on environmental control to minimize stress, i.e., preventive management. As further microbiological control techniques come into practice, some of the major disease problems can be addressed. However, I will not discuss these techniques further since my main focus in this article is the shrimp diseases themselves. It should nevertheless be noted that development of microbiological control techniques does not mean that the basic science of shrimp biology and pathology should be ignored; on the contrary, it is more urgent than ever. Below we will discuss the problem of shrimp disease and possible strategies to help develop solutions.

DISEASE PROBLEMS

In this section I will first discuss the size of the problem. The main disease threats will be presented, including viruses, bacteria, rickettsia, fungi and protozoa. This is followed by a brief outline of where these diseases have been occurring, as well as other environmentally related diseases. Finally, I will try to provide some predictions of what is likely to happen over the next few years in terms of the spread of disease.

How Large Is the Shrimp Disease Problem?

In order to quantify the size of the disease problem I have made some preliminary calculations that are summarized in Table 1. The data is largely based on calculations done by Rosenberry in 1993 and 1994. Thus in a few cases government statistics and other sources were also used. Overall there is a lack of reliable information. The table is by no means complete and should not be used as anything other than an indication of the extent of the disease problem.

There are several countries, such as Thailand and Ecuador, that have faced significant disease problems but maintained a high level of production. The total losses for these countries are very difficult to estimate. Further more the present data reflects information and assessments from several sources, in order to give the widest possible perspective to the problem. There are a number of cases where significant disease problems affect one part of a country, while in other parts production is expanding, thus compensating for the loss. The total figures for such countries as Bangladesh, Indonesia and India do not reflect the significant problems in several farming areas established early on. The collapse in Chinese farmed shrimp production has led to a large scale shift from this species to others such as fish, crabs and mussels. The shrimp farming collapse has also had significant effects on the wild shrimp harvest in the Yellow Sea, which decreased by 90% in 1993, mainly due to disease (Zweig 1995).

If we calculate an average price of shrimp at about US$ 5 per Kg for heads-on shrimp and total disease-related losses are 540 000 metric tons, the total annual loss based on 1994 data would be US$3 billion. This indicates a very significant problem that has implications for the well-being of millions of people in developing countries. Below I will provide a short description of some of the main disease problems and the state-of-knowledge to date.

Table 1. Estimated Effects of Disease on Shrimp Production in Selected Countries

Country	Thailand	Philippines	Ecuador	Indonesia	China	Taiwan	Mexico	USA	India	Vietnam	Bangladesh	World
Year of Peak Production	1994	1989	1992	1991	1992	1987	1994?	1993	1994	1994	1994?	1994
Estimated Fresh Peak Production**	225	59	126	149	215	139	12	3	70	50	35	733
Estimate Value of 1994 Production*	225	39	199	199	35	25	12	2	70	50	35	733
Estimated Loss to Disease**	130?◆	57◆	34⌘	50⌘	180✸	100■	1?⌘	4.5?⌘	25?⌘	10?■	5■	541
Percentage Loss Due to Disease	58	45	34	50	514	400	8	150	36	20	14	74
Value of Production Loss*	650	284	170	250-	900	500	5	60●	125	50	25	3019

? = Unconfirmed data

* = Estimated value in million 1994 US$

** = in thousand metric tons

Sources: ◆= Shariff, M. (1995) *Fish Health: An Odyssey Through the Asia-Pacific Region*

⌘= Rosenberry, B. (1993) (1994) *World Shrimp Farming*

✸= Zweig, R., Personal communication

■= CNZ, ESPNOL & CENAIM. *Proposal for Laboratory of Disease Diagnosis*

●= Stevens., L. (1995) *Fish Farming News* 4.

What Kind of Diseases Are Most Important?

This is a very difficult question to answer. In general it can be said that diseases are related to the types of stress that the shrimp undergo during propagation. Consequently, the more we know about optimal environmental conditions for sustaining shrimp and enhancing their immune defenses, the more we can improve shrimp health. Which pathogens are most difficult to address? It seems increasingly clear that diseases of bacterial and fungal origin can be more easily dealt with through changing the pond or hatchery environment. On the other hand, once a virus has started to spread, it is very difficult to contain. There are no methods as yet to treat or vaccinate shrimp. If we look at lessons from human and animal health, it is also clear that viral diseases are very difficult to treat. Progress in research takes a long time and considerable resources are needed. Under poor farming conditions, however, it is often the opportunistic diseases like bacteria, fungi and protozoa, that are constantly present in the pond environment, which cause the most deaths. The common practice of inducing spawning in broodstock, at too frequent intervals also leads to poor quality seeds and more opportunistic disease.

Viruses

More than 15 different viruses have been identified from Penaeid shrimp over the past twenty years (Fulks *et al*, 1992) (Bower *et al*, 1994). Many of the known viruses infect larvae and juveniles and can be quite specific in terms of which species are infected. Viruses can be triggered by the following types of stress: overcrowding, temperature fluctuations, low oxygen levels or high levels of pollutants. They can be divided into two broad categories: **DNA viruses** such as baculovirus (BNV, BP, MBV and YBV), hematopoietic necrosis virus (parvovirus), (IHHNV), hepatopancreatic parvo-like virus (HPV), iridovirus, and **RNA viruses** such as aquareoviruses, nodavirus, reo-like virus (Reo) rhabdovirus and toga-like virus. It is clear that new viruses will be found in the next few years, like the gut and nerve syndrome (GNS) agent. It is quite possible that some of the worst viral epidemics are still to come in view of the fact that shrimp farming is being introduced to Africa and Madagascar where new diseases might be encountered. Our current knowledge is insufficient to make any estimates of the extent of these diseases.

The only short term solution to viral disease is to improve health management to make infection less likely. The medium term solution is, on the one hand, to invest significant amounts in research and on the other, to ensure that the correct diagnosis is made so that appropriate measures can be taken to halt the spread. Table 2 gives order of magnitude investment needs in shrimp disease research and associated areas; for viral disease research, the absorptive capacity is on the order of US$ 2 million per year. Efforts could also be directed to developing strains of the more important cultured species that are resistant to the most damaging viruses. Finally, a long-term strategy might include genetic transformation as well as strengthening the shrimp immune system to enhance survival.

Bacteria

Many different forms of bacteria can potentially infect shrimp, frequently as opportunistic follow-on to viral infection or environmental stress. Most of the disease outbreaks to date have been concentrated in the following categories: Vibrio bacteria, *Pseudomonas sp*., *Citinoclastic* bacteria, *Luminous* bacteria, *Leucothrix sp* and *Thiothrix sp*. Bacteria have been particularly damaging in poor hatchery environments as well as other high stress situations. Many of these bacteria can infect a broad range of shrimp species and exist naturally all over the tropics (Fulks *et al*, 1992) (Bower *et al*, 1994).

The short term strategy for dealing with bacteria has been the use of antibiotics as well as improved pond cleaning and an increase in water exchange. Bacterial resistance in the hatchery environment could also be improved by putting a stop to poor seed stocking practices with their too frequently induced spawnings. Medium term strategies might include enhancing the bacterial composition of the pond culture, and manipulating the hatchery environment in new ways to avoid the use of antibiotics. A long term strategy could focus on developing strains resistant to the main bacterial pathogens, particularly for production bottlenecks like hatcheries. Another possibility would be to develop sturdier shrimp strains capable of surviving poorer conditions and higher levels of stress.

Rickettsia

Rickettsia are rod-shaped micro-organisms that cause disease in many different types of organisms. At this time only a couple of rickettsia-like diseases have been described in shrimp: Texas necrotizing hepatopancreatitis in *Penaeus vannamei* (TNHP) and rickettsia-like infection of Pandalus (Bower *et al,* 1994). The current state of knowledge on rickettsia-like agents is quite poor. Thus it is difficult to assess the gravity of the problem. Currently there is a desperate need for new immunological testing methodologies that would permit proper diagnosis. The research strategy to address rickettsia-like agents would resemble that of bacterial diseases.

Fungi

The main groups of fungi reported to infect shrimp include: *Lagenidium callinectes*, *Sirolpidium sp*., *Haliphthoros sp*., *Hyphomyces sp*., *Saprolegina parasitica*, *Leptolegnia marina* and *Fusarium solani* (Bower *et al,* 1994). Fungal diseases are quite common in shrimp and crayfish and the example of the European Freshwater crayfish is reason to take these diseases very seriously. A fungal disease introduced from North American has essentially doomed the native Freshwater crayfish in Europe. After the spread of the disease the North American Signal crayfish was introduced to replace the extensive losses of the indigenous crayfish. The Signal crayfish can carry chronic fungal infections and is consequently undermining the future of the European Freshwater crayfish (Unestam and Söderhäll). Similar situations could very well develop in shrimp over the next few years as species for cultivation as well as harvested raw shrimp, both of which could accidentally be carriers, are transported between continents. While there have been some problems with fungal diseases, particularly in hatcheries, as more becomes known about such diseases, it should be possible to address them through better control of the hatchery environment. Risks from disease during growout stages are in some ways more alarming, since it can be very hard to get rid of fungus once it has a foothold (Fulks *et al*, 1992).

The research strategy in the short term should focus on building a wider knowledge of which fungi infect shrimp and in particular if there are any cross continental sensitivities, similar to the European Freshwater crayfish situation, that could threaten whole industries. Improving the hatchery environment and finding optimal ways of cleaning out tanks to prevent infection are also efforts that can be undertaken now. In the medium term, sensitive immunological and molecular tests for the presence of the most infectious diseases and for strains with a greater resistance to fungal infection could also be developed. In the long term, genetic transformation of some of the key Penaeid species could include resistance to the worst killers and broad defenses against fungal diseases. Another long term goal is the description of all the major diseases caused by fungi.

Protozoa

Protozoa are unicellular animals, present naturally in shrimp cultures, that can cause considerable damage, particularly under poor farming conditions. The main disease agents are: *Epistylis*, *Vorticella*, *Zoothamnium*, *Ephelota gemmipara*, *Acineta*, *Gregarines* and *Microsporidians*. Many protozoa are most harmful in extensive shrimp farming where other organisms such as fish or bivalves are present in the ponds. Losses are often related to high stress pond environments as well as hatcheries (Fulks *et al*, 1992), (Bower *et al,* 1994).

A short term strategy is to improve the general health management of hatcheries, including reducing the use of chlorine in the pond environment and growout ponds to limit the impact of protozoa. A medium term strategy is developing simple diagnostic kits for screening against harmful levels of protozoa, particularly internal parasites such as *Gregarines* and *Microsporidians*, so that effective countermeasures can be taken. Improving the use of probiotics could be one possibility. The long term strategy should include finding effective prevention and treatments against the most serious protozoa, as well as ways of enhancing the shrimps' own immune system.

Nutritional, Toxic and Environmental Diseases

A whole range of disease symptoms are related to poor farming conditions: chronic soft-shell syndrome, red disease, fatty infiltration of the hepatopancreas, blue disease, cramped tails, hemocytic enteritis, heavy metal poisoning, black gill disease, muscle necrosis, floating head syndrome, deformity disease, body cramp and gas bubble disease (Fulks *et al*, 1992), (Bower *et al,* 1994). There are also many different symptoms that may be related to culture conditions rather than to a particular infectious agent, but that might be diagnosed as an infection. It is likely that the more we learn about these diseases and how to improve shrimp culture conditions, the less common they will be. In the early stages of shrimp farming, some of these diseases that caused high mortalities and outbreaks are still common. However, the risk of epidemics is not present, and counteracting these diseases is considerably easier, provided overcrowding and over-establishment of ponds can be controlled. Improvements in feed have also reduced the risks for several of these diseases.

A short term strategy is to improve the general management of the pond environment and the quality of shrimp feed. A medium term strategy involves a better understanding of shrimp biology in terms of nutritional requirements, water quality, suitable soils for pond construction, toxicity of various types of compounds as well as other environmental requirements. A long term strategy is to improve the strains to permit farming in what are currently marginal areas, as well as finding a combination of farming techniques that permits more integrated systems.

What Are the Trends in Diseases?

Shrimp diseases are here to stay, and they are far from peaking, with current levels of disease reaching over 50% of the world's farmed shrimp. It is likely that we will see a shift in the main killers away from environmentally related mortalities toward viruses, fungi and bacteria. Overall the situation is going to get worse before it gets better. It is quite possible that one of the current cultured species will be particularly sensitive to some form of infectious disease and will have to be replaced by another species. As farming techniques improve, there should be many possibilities to avert mass mortalities through proper treatment. The use of diagnostic kits and the establishment of testing-labs closer to the farms will permit a better understanding of pathology and many more disease causing agents will be described.

CURRENT STATUS OF RESEARCH EFFORTS ON SHRIMP DISEASE

Developing Countries

Research on shrimp disease and biology has been growing over the past few years, but the total number of researchers is still very low. In terms of government-sponsored research, Thailand, China, Mexico and Ecuador are the key countries. Most research has been devoted to developing diagnostic tools to characterize diseases and make epidemiological surveys. There has been some work done on understanding the basic biology of shrimp ponds and what should be done to keep them functioning. In no case has an effective vaccine or cure for viral diseases been developed. Some effective treatments for bacterial infections have been developed, resulting in a reduction of loss.

In the shrimp industry in developing countries, there has been some applied research on how to counteract losses to disease. This has included research on improving the quality of feed as well as understanding and preventing the spread of disease. There have been some efforts devoted to probiotics and several attempts to find natural products that enhance shrimp health. Investment in this sector is the most promising sign on the horizon. However, the knowledge base required to address many of the diseases at hand is not sufficient to provide most developing country-based companies the incentive to investigate treatment techniques. Total developing country investment to address shrimp diseases is estimated at less than 0.5% of the total losses of US$ 3 billion. If this level of effort is compared to the development of the salmon industry in Norway, it is clear that the level of investment in shrimp diseases is extremely low. A culture change is needed in the private sector to use science and implement the new findings in the management field. Another important cultural change is for the developing country industry to follow the example of industrial country industries and spend a bit of the profits into making the business sustainable.

Industrialized Countries

Most of the knowledge about shrimp immunology and genetics is concentrated in a few groups in the major Organisation for Economic Co-operation and Development (OECD) countries. Many of these groups have been working with insect immunology for the development of pesticides, but some have also dealt with shrimp, crayfish and lobsters. While fish and chicken immunology is well developed, it is too dissimilar to shrimp to apply many of the scientific advances on that front. However, it appears possible to build on existing knowledge about insects, particularly in terms of bacterial and fungal diseases. Viral diseases, on the other hand, are a new field in which very little has been done to date. One country that faced problems in shrimp disease early on and is trying to address it through building a research base is Taiwan.

Since relatively little is at stake in OECD countries, there has not been a particularly strong emphasis on advancing research in this field. While lobster farming or ranching has been tried in the United States, Norway and Canada, it has been undertaken without the support of a scientific base. Crayfish farming has also been developed in Sweden, United States, Norway, Finland, Australia and New Zealand, but the industry has been unable to support any private research enterprises. Research related to aquaculture development has largely focused on finfish and to a very limited extent on shrimp. There have been some technology developments in shrimp culture techniques in the United States, Japan and Taiwan that have implications for health management. The total investment in industrialized countries probably matches the efforts of developing countries, but the science is more basic and less applied than in developing countries.

ANALYSIS OF CURRENT RESEARCH EFFORTS

Below I will attempt to analyze why so little has been done to understand shrimp diseases and identify the main constraints to advances in scientific development.

Why Has So Little Been Done?

The overriding reasons for the low level of effort can be found in economic aspects of shrimp farming. Highly unsustainable practices with a very short time horizon have been possible because of low land prices and the fact that environmental costs have been treated as negligible externalities. There has been no incentive to limit growth or profit taking since there is plenty of land and environmental costs have never been internalized in the economics of shrimp farming.

When we look at the world's accumulated knowledge on shrimp biology relating to diseases, it is clear that the list of what needs to be done is very long. One hypothesis why shrimp disease has not been seen as a development priority in equatorial countries is that mechanisms for international collaboration on research and development are inadequate. Shrimp diseases are largely an equatorial country problem, and available knowledge world-wide is insufficient to address it. To date, most knowledge about shrimp immunology has come through the study of insects for pesticide development and the molecular biology of crayfish immunity. There has also been some work done on insects with regard to the study of viruses and bacteria, but very little on crustaceans. Consequently there is a need for a massive effort to bring the state of the art to an appropriate level to address the issue of shrimp disease, and most of the work will have to be done in developing countries since that is where the problem is concentrated. Research on viruses, for example, often requires live samples and easy access to farming sites. Since there are few economic stakes involved for developed countries, this research has not been of great interest in the past. Agriculture research lobbies have not been very interested in including aquaculture as part of their mandate. Shrimp farming has also been the victim of its "boom and bust" cycles, attracting private investors with time horizons as short as a year, who have not been particularly concerned with taking collective action to apply scientific developments to the field.

Since much of the basic research still remains to be done before any patents can be valuable, it is hard for private companies to pursue this field. The collective knowledge to put commercial applications within the grasp of private firms needs to be acquired. There are obvious problems regarding ownership of findings on treatments and health management developed in one country and used by others. In addition, many treatment methods developed to date employ readily available chemicals and antibiotics, thus making it difficult to "sell" more advanced and costly treatment techniques to farms. These factors have delayed private efforts in the field.

International assistance institutions have been slow to aid developing countries in building a capacity to address shrimp disease issues. The aquaculture health institute in Thailand has been one leader in this field together with the Faculty of Fisheries and Marine Science at University Pertanian in Malaysia. Assistance in this field has been provided by the UK Government's Overseas Development Administration in their South East Asia Aquaculture Disease Control Project (Chanratchakool 1994). Despite these efforts, there remain substantial gaps in assistance and the majority of agencies are doing too little to effectively address the problem. Aquaculture biotechnology is a clear example of the inability of international assistance organisations to address a multi-billion dollar problem, despite a very large potential return on investment. The lack of co-ordination among the agencies, together with poor mechanisms for identifying gaps in support, is partly to blame.

With regard to funding mechanisms for shrimp disease research, the World Bank, the United Nations Development Program (UNDP) and the regional development banks, together with bilateral donors, would be the obvious institutions. No specific projects have been funded, however, perhaps with the exception of a shrimp disease project for Ecuador that is currently being considered by the World Bank. The main reason for this seems to be the limited ability of these institutions to address marine biotechnology (Zilinskas and Lundin 1993) particularly on the level of the task managers responsible for developing the projects. Calculating rates of return from science-based projects such as biotechnology programs has also been lagging behind, so it is considered difficult to quantify the direct benefits of such investments. Without the ability to quantify the benefits, finance ministries in the borrowing countries might not consider making such investments. Changes in international assistance mechanisms have thus far proven to be slow. Effective change will require commitment from both the management of the institutions as well as the ministries responsible for policy guidance.

The structure of science institutions on the receiving end (in the shrimp farming countries) may also make it difficult to initiate international assistance programs. Limited international collaboration also makes it difficult to achieve progress and maintain contact with the larger scientific community.

What Are the Limiting Factors to Taking Action?

Action has been limited by a whole set of different constraints:

(i) insufficient mechanisms exist for international collaboration on research and development, partly due to institutional structures;

(ii) the culture of most decision makers is not conducive to using scientific data when making decisions;

(iii) the institutional structure and policy framework of international assistance efforts are inadequate;

(iv) there is a mismatch between industry culture and science in most developing countries;

(v) the knowledge about what needs to be done about shrimp diseases is not available to decision makers;

(vi) there is a lack of financial resources to address the problem;

(vii) the field is too new to be internationally recognized by both research communities and donors; and

(viii) there is limited knowledge in most developing countries of the nature and extent of shrimp disease.

These factors have also affected the development of the broader field of marine biotechnology, which includes shrimp disease (Lundin 1995). I have found that among these factors, the most important are (i), (ii), (iii) and (iv).

Given all these constraints, what could be a possible strategy to address the problem of shrimp disease? Below are some suggestions for such a strategy.

POSSIBLE STRATEGIES TO ADDRESS SHRIMP DISEASES

To address shrimp disease, research strategies will be needed in the fields of:

(a) genetics;

(b) immunology;

(c) pathology, including diagnostics, virology, parasites and bacteriology, nutrition and shrimp toxicology; and

(d) enhancement of seed quality and specific pathogen free broodstock .

Although I briefly discussed a few possible research fields above, I will now attempt to look at these four research areas and how to approach them. For estimates of costs and time requirements please see the financial needs section.

Genetics

There are three main avenues in genetics that can be pursued: (i) population genetics; (ii) selecting for survival genes; and (iii) genetic transformation of broodstock.

Population genetics can include such things as identifying markers in the genome, studying mitochondrial DNA, and understanding and controlling mechanisms for cell differentiation, embryology and genetic regulation. It is important to have knowledge of intra-species diversity as well as that of the various cultured species of shrimp. Building a repository of different genetic varieties in nature as well as in the research laboratory could enhance the ability to counteract diseases in the future.

Selecting for survival genes can be accomplished by studying resistance to virus and other infections through collection of survivors of epidemics, working with resistance in hatcheries and traditional selection of specific properties such as resistance to specific environmental conditions.

Genetic transformation of broodstock can be accomplished by working with inbred strains (requiring 14 generations of inbreeding) or by introducing genes from other species or even classes of organisms to enhance desired properties. In the case of viral resistance, this could include expression of viral genes, antisense\ribozyme or immune genes. This will require considerable effort and basic research before the results can be applied in aquaculture. The development of disease-free broodstock and adding specific resistance's against particular virus or bacteria might also make sense (Lundin and Zilinskas, eds., 1995), (Colwell *et al*, 1994).

Immunology

There are two main areas of immunology that need to be developed: shrimp immunology and diagnostic immunology. Shrimp immunology includes issues such as: a basic understanding of the shrimp immune system and what inhibits its functioning; what can be done for immune stimulation and what mechanisms of probiotics could protect shrimp; building on findings in insect and crayfish immunology for further immune enhancement against specific pathogens; and identifying the effects of stress on the shrimp immune system. One recent preliminary study states that using Beta 1,3 Glucan as immune stimulants of macrophage like cells increases the non specific microbicidal and phagocytic capacity of the infected shrimp. A Texas based company is selling the product called ImmuStim and claims it has positive effects on Taura syndrome infected shrimp (ImmuDyne 1995). Four different products are being developed at this time: larval feed, juvenile feed, growout feed and broodstock feed.

Diagnostic immunology involves pathogen diagnosis, through new histological and bacteriological techniques. The development of immunodiagnosis techniques such as specific monoclonal antibody-based diagnostic kits or nucleic acid probes are important for epidemiological studies. In particular, by using such simple techniques as the enzyme-linked immunosorbent assay (ELISA), detection can be made early on in the infection of a pond or hatchery and measures can be taken to prevent the spread. Monitoring stress phenomena in ponds, through the development of appropriate kits, including environmental and nutritional factors, would also be an important shrimp health management tool.

Pathology

The pathology field is divided into several different areas of important research: diagnostics, virology, parasites and bacteriology, nutrition and shrimp toxicology (Bower *et al*, 1994). Outside of the immuno-diagnostic tools mentioned above there is a whole field of diagnostic methodologies that need to be developed and standardized for shrimp diseases. Light and electron microscopy have been used with some success in the past on viral, bacterial and fungal infections and standardized practices would be very useful in this field. Development of serological kits that could be easily applied in the field would also be valuable. Although some work has already been done in this area, dissection techniques could benefit from further standardization. Tissue culture techniques need to be improved and permanent cell lines established. Establishing techniques to differentiate between multiple pathogens and standardizing such diagnoses will also be of importance. Setting priorities for which pathogens methodologies should be developed also needs to be done on a continuing basis. (Fulks *et al*, 1992). For a few points on development of a research agenda in virology, parasites and bacteriology, and nutrition and shrimp toxicology, please see disease section above.

Enhancement of Seed Quality and Specific Pathogen Free Broodstock

The steady supply of good quality seed stock is a major constraint in shrimp farming today. To improve quality, there is a need to develop sustainable spawning practices, and to enhance the chances of survival of the fry through improving the hatchery environment. Much of this work should focus on understanding the basic biology of shrimp reproduction, but there might also be some opportunities for development of biotechnology tools.

Specific pathogen free broodstock has been widely advocated, particularly in the USA, as the primary way to avoid disease problems in shrimp. However, I would contest this, since pathogen free broodstock may be even more susceptible to infection once it is introduced into the normal culture environment. A genetically transformed and enhanced broodstock, on the other hand, should stand some chance of resisting certain types of infections. It is probable, however, that collecting wild post larvae, when possible, will remain the most viable option for quite some time to avoid most pathogens and to maintain a genetically differentiated stock with greater chances of survival. Nevertheless, tapping wild populations as a basis for broodstock has serious biodiversity implications that need to be considered. The research agenda should thus include developing the quality of hatchery output to a level where this becomes the superior way of stocking growout ponds. Specific pathogen free broodstock in a combination with enhanced properties might be more attractive in the future.

THE NEED FOR INSTITUTIONAL CHANGES

There are many institutional needs that should be addressed, among them: creating a functioning global consortium to address shrimp diseases; setting a global research agenda; and developing an industry approach to health management. In the recent past, some attempt has been made to develop such a consortium. In April 1992, at a workshop in Hawaii on diseases of cultured Penaeid shrimp in Asia and the United States, some initial attempts were made to stimulate collective action through the Asian Fisheries Society and the American Fisheries Society. The Network for Aquaculture Centers in Asia-Pacific (NACA) is another regional body that has made some progress in coordinating efforts in the disease field through the appointment of lead centers on specific aquaculture related topics. In November 1993, a conference on Marine Biotechnology in Asia and the Pacific brought researchers from Europe, Latin America, the United States and Asia together and gave them an opportunity to coordinate some of their strategies in joint actions. One of the outcomes was a recommendation to establish a research network in Asia and Latin America to coordinate some of the efforts and exchange ideas and diagnostic tools (Lundin and Zilinskas, eds., 1995). An invitation to found an International Commercial Aquaculture Research Institute (ICARI) was distributed at that meeting with the objective of getting collective action among the firms that are currently suffering losses due to disease. Among the proposed activities are the following: setting up an information service; sharing consortium research programs; enhancing genetic stock; establishing SPF stocks and health and hygiene standards; providing environmental assessment capability and analytical and advisory services (NSTDA 1993).

While overall, the situation is still far from addressing many of the challenges facing the shrimp industry due to disease, some additional attempts at collective action have been made over the past few years and significant progress has been achieved toward addressing some of the more acute questions. An example of such an effort is EU financing of the Ecuadorian Centro de Servicios para los Productores de Acuicultura in Guayaquile, where research on *Penaeus vannamei* disease is being conducted. The center was developed to serve the needs of the producers and to improve health management of shrimp. By giving private industry the possibility to control the direction of the services, it is believed that the usefulness of the undertaking will be more client oriented. A World Bank project has been discussed along these lines, where private industry would form a consortium and finance half of the facilities and operations and a World Bank loan to the government would fund the remainder. At this point in time it is unclear whether this project will actually be implemented. The institutional model does, however, seem quite attractive in several of the larger producing countries.

Creating an International Shrimp Disease Network

The creation of such a network was proposed to the World Bank in 1994 by Colwell, Carrera and Mialhe. It could comprise of national, regional and reference laboratories.

Since this is an issue requiring emergency action, pooling global resources makes good sense. National laboratories could be responsible for routine epidemiological control of pathogens, water quality testing and measurements of stress. By building on existing research institutions, this would require about US$ 100,000 annually per country involved. Three regional laboratories in Ecuador, Thailand and China could be responsible for each of the three main Peneaus species cultivated. In all three countries there are efforts to create such facilities at this time, but additional resources and coordination might be needed. The focus could be on determination of disease etiology, preparation of molecular probes, development and standardization of diagnostic kits and training of students and technicians of national laboratories. Annual costs for running these facilities would total about US$ 0.5 million.

The reference laboratories could consist of about 10 different existing teams located in Europe, USA, Canada, Australia and Japan. They could primarily focus on basic science in: diagnosis, bacteriology, virology, immunology and genetics as well as advanced training such as Ph.D. programs. Their work needs to be closely coordinated with the reference laboratories in order to focus on some of the critical research needs. The estimated annual cost of such laboratories would be about US$ 1 million.

This is just one example of how to structure such efforts, and it is clear that something along these lines would be very useful. The distances between the existing researchers and the limited number of fora available have slowed this process down considerably, but the time is ripe for concerted action.

FINANCIAL NEEDS

Financial mechanisms to fund shrimp disease research and equitably distribute the benefits are desperately needed. As mentioned above, the total costs of creating and operating a scientific network might not be very high, perhaps on the order of US$ 10 million per year for the work related to shrimp disease. By including aspects of shrimp health management, the total figure would probably be on the order of US$ 30 million. If we consider the 1994 losses at about US$ 3 billion, this would be about one percent of the global losses, or about 3% of Chinese losses. In the medium term there will be increasing needs to expand efforts and some of the new applied research facilities can effectively use additional resources. A level of around US$ 90 million would seem reasonable given today's information, but this is figure is only a rough estimate. Most of the funding would need to come from within the industry itself, but it is likely that the availability of matching government grants from some of the larger producing nations would speed up the process.

For the funding to be successfully applied, there are, however, a number of institutional issues that need to be resolved. Creating new institutions and financial mechanisms tends to be time consuming and could very well delay the implementation of some of the recommendations generated in this paper for several years.

Table 2. Order of Magnitude Investment Needs in Shrimp Disease Research and Associated Fields over the next 15 years. A total amount for shrimp disease in the order of US$ 275 million over this 15 year period seems reasonable, but should be taken as a rough estimate.

Types of Shrimp Diseases Research	**Investments**		
	Years 1-2	**Years 3-7**	**Years 8-15**
	(US$million per year)		
Viral	2	5	5
Bacterial	2	5	5
Rickettsia	0.5	0.5	1
Fungal	2	3	3
Protozoan	0.5	0.5	1
Nutritional, Toxic and Environmental	3	5	5
Total Disease Research Costs (for all years included)	20	95	160
Associated Funding Needs in Shrimp Farming			
Health Management	10	30	50
Culture Technique Improvements	10	50	30
International Network on Shrimp Disease	1	1	1
Diagnostic Technology Development	2	2	1
Environmental Control Technologies (Probiotics)	3	3	3
Feed Improvements	5	5	5
Total Research Needs per Year	31	91	90

CONCLUSIONS

In this paper the main focus has been on how to address the issue of rampant shrimp disease. The mismatch between the scientific establishment and the shrimp farmers in many developing countries, has meant that the knowledge base is insufficient to address the many management needs. In the short term this could mean that some public investment might be needed to leverage private investments and get collaborative networks on shrimp research up and running. In the medium to long term, most of the investments in research will have to be made by the industry itself.

If shrimp farming is to become a sustainable activity, a drastic change in practices is needed, particularly on the management side, in order to internalize the high environmental costs. This can only happen if the regulatory framework is in place to encourage sustainable practices. Much of this issue is related to the availability of coastal land, and the rights of land tenure holders versus shrimp farm owners. The institutional solutions to these problems are quite complex and varied, depending on countries and legal traditions. Establishing systems for sustainable management, based on carrying capacity and absorptive capacity, will be a major challenge for the shrimp farming industry over several years to come.

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